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Part 2

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## Preface

The major space goal of the National Aeronautics and Space Administration's Office of Aeronautics and Space Technology (OAST)<sup>†</sup> is to provide enabling technologies—validated at a level suitable for user-readiness—for future space missions, in order to ensure continued U.S. leadership in space. An important element in accomplishing this goal is the *In-Space Technology Experiments Program (IN-STEP)*, whose purpose it is to explore and validate, in space, advanced technologies that will improve the effectiveness and efficiency of current and future space systems.

On December 6 through 9, 1988, almost 400 researchers, technologists and managers from U.S. companies, universities and the government participated in the **OAST IN-STEP 88 Workshop\***. The participants reviewed the current in-space technology flight experiments, identified and prioritized the technologies that are critical for future national space programs and that require verification or validation in space, and provided constructive feedback on the future plans for the **In-Space Technology Experiments Program**. The attendees actively participated in the identification and prioritization of future critical space technologies in eight major discipline theme areas. The content presented in the two parts of this NASA Conference Publication (CP), each under separate cover, reflect an overview of the workshop participants' efforts to review IN-STEP planning for the future of the program. These critical space technologies will help focus future solicitations for in-space flight experiments.

At the workshop, Dr. Harrison H. Schmitt emphasized that the nations which effectively exploit the advantages of space will lead human activities on Earth. OAST has worked closely with the aerospace community over the last few years to utilize the Space Shuttle, expendable launch vehicles, and, in the future, *Space Station Freedom*, for experimentation in space in the same way that we utilize wind tunnels to develop aeronautical technologies. This close cooperation with the user community is an important, integral part of the evolution of the **In-Space Technology Experiments Program** which was originated to provide access to space for technology research and for experimentation by the entire U.S. aerospace community.

The PREFACE edited for this NASA Conference Publication is based on the *IN-STEP 88 WORKSHOP* handout foreword written by Dr. Leonard Harris, Chief Engineer, Office of Aeronautics and Space Technology.

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<sup>†</sup> The Office of Aeronautics and Space Technology has since been renamed the Office of Aeronautics, Exploration and Technology (OAET). In conjunction with this change, the scope of the Human Exploration Initiative (HEI) has been broadened and renamed the Space Exploration Initiative (SEI).

\* The **IN-STEP 88 Workshop** was conducted by the Space Station Freedom Office of the Langley Research Center. Questions regarding this workshop should be directed to Dr. Roger A. Breckenridge, Deputy Manager, Space Station Freedom Office, M.S. 288, NASA Langley Research Center, Hampton, Virginia, 23665.

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# Introduction

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop December 6-9, 1988, on the **In-Space Technology Experiments Program (IN-STEP)** in Atlanta, Georgia. The purpose of this workshop, *IN-STEP 88*, was to identify and prioritize space technologies that are critical for future national space programs and which require validation in the space environment. A secondary objective was to review the current NASA (**In-Reach**) and industry/university (**Out-Reach**) experiments.

Finally, the aerospace community was asked to review and comment on the proposed plans for continuation of the **In-Space Technology Experiments Program** itself. In particular, this review included the proposed process for focusing the next experiment selection on specific, critical technologies as well as the process for implementing associated hardware development and integration on the Space Shuttle vehicle.

The product of the workshop was a prioritized listing of the critical space technology needs in each of eight technology disciplines. These listings were the cumulative recommendations of nearly 400 participants—including researchers, technologists and managers—from aerospace industries, universities and government organizations. The identification and prioritization of the critical space technology needs were initiated by assigning NASA chairpersons (theme leaders) to the eight major technology discipline themes requiring consideration. These themes were as follows:

- ① *Space Structures*
- ② *Space Environmental Effects*
- ③ *Power Systems and Thermal Management*
- ④ *Fluid Management and Propulsion Systems*
- ⑤ *Automation and Robotics*
- ⑥ *Sensors and Information Systems*
- ⑦ *In-Space Systems*
- ⑧ *Humans in Space*

In order to afford further structure within each theme, the chairpersons divided their themes into three theme elements each. The theme element concept allowed focused technical discussions to occur within the broad discipline themes. For each theme element, the theme leader selected government, industry and university experts to present the critical space technology needs of their respective organizations. The presentations were reviewed and discussed by the theme audiences (other members of the aerospace community), and prioritized lists of the critical technologies in need of verification and validation in space were established for each theme element. The comments and conclusions for each theme were incorporated into a summary listing of the critical space technology needs as well as associated flight experiments representing the combined inputs of the speakers, the audience, and the theme leader.

The critical space technology needs and associated space flight experiments identified by the participants provide an important part of the strategic planning process for space technology development and provide the basis for the next solicitation for space technology flight experiments. The results of the workshop will be presented in the **IN-STEP Selection Advisory Committee** in early 1989. This committee will review the critical technology needs, the funding available for the program, and the space flight opportunities available to determine the specific technologies for which space flight experiments will be requested in the next solicitation.

## ***Conference Publication Content Description, Parts 1 and 2***

The proceedings handbooks were organized as three presentation categories in four volumes: (1) Overview (Executive Summary volume), (2) In-Reach/Out-Reach experiments and the experiment integration process (Volume I), and (3) critical technology presentations (Volumes II and III). For presentation in this NASA Conference Publication (CP), a two-part set (under separate covers), the Executive Summary and Volume I are combined in Part 1 and Volumes II and III are combined in Part 2.

### **Part 1**

**Keynote Address** — Part 1 of the IN-STEP 88 CP set opens with the keynote address presented at the workshop banquet by Dr. Harrison Schmitt, a former U.S. Senator and Apollo astronaut, on the 16th anniversary of his lunar launch (Apollo 17). In his presentation, Dr. Schmitt outlined his vision for the future of the U.S. space program by describing a *Millennium Project* which would combine space ventures to the Moon, to Mars, and to planet Earth.

**Executive Summary** — The *Executive Summary* (first half of Part 1) contains the welcome and workshop instructions, strategic planning for the in-space technology experiments, an overview of the space technology experiments being conducted in OAST as well as the solicitation process for IN-STEP, the proposed accommodation process for *Space Station Freedom*, and the critical-technology-needs summaries for each theme. These summaries are presented in a standardized format version of the lists prepared in "real-time" at the workshop.

The *Welcome and Workshop Instructions* describes the purpose, the process, and the product intended for the workshop. The *Space Strategic Planning* process describes the OAST space research and technology base programs which generate new technology concepts in the major discipline areas, the new focused programs of the Civil Space Technology Initiative (CSTI) as well as the Pathfinder, and provides funding for the industry, university and NASA space technology experiments. Overview charts of current OAST sponsored space flight experiments and specific information regarding the IN-STEP solicitation process are provided to establish an understanding of space technologies currently validated and the proposed approach for initiating new experiments.

Brief overviews of the objectives, technology needs/backgrounds, descriptions, and development schedules for current industry, university and NASA space flight technology experiments are presented in the second half of Part 1 (Volume I of the original workshop handbook set). This was a very important part of the workshop, providing an opportunity for the aerospace community to interact with experimenters and provide feedback on the flight experiments. An overview of the user/payload integration and accommodation process being established for use on *Space Station Freedom* is included in the content of Part 1 **Experiment Descriptions** to promote better understanding within the space experiment community, and presentations describing the experiment integration process are presented at the end of Part 1.

### **Part 2**

**Critical Technologies** — Part 2 of the IN-STEP 88 CP set combines the contents of Volumes II and III of the original handbook set. This book contains a theme introduction by each chairperson, critical technology presentations for each of the theme's three elements of technical focus, and summary listings of critical space technology needs for each theme. The introduction for each theme includes the chairperson's overview and instructions for the participants. The critical technology presentations, along with summaries listing the critical space technology needs and associated flight experiments, are presented as previously described.



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<sup>†</sup> Part 1 of the IN-STEP Workshop Conference Publication two-part set is under separate cover.

<sup>‡</sup> Dr. Ambrus' presentation for the IN-STEP 88 Workshop was given by Dr. Harris.

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Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

Background and Objectives

*Theme Orientation and Recap of In-Space RT&E Workshop (Williamsburg, '85)*

Martin M. Mikulas, Jr.  
NASA Langley Research Center, Hampton, Virginia

### ORGANIZATION

**THEME LEADER:** Martin M. Mikulas, Jr.

**COMMITTEE:** Murray S. Hirschbein, OAST/RM  
Harold Frisch, GSFC  
John A. Garba, JPL  
Dale C. Ferguson, LeRC  
Richard W. Schock, MSFC  
Robert J. Hayduk, LaRC  
Claude R. Keckler, LaRC  
Plus Subtheme Speakers

**SUBTHEMES & THEME GROUPS:**

1. Structures
2. Control/Structure Interaction
3. Controls

### THEME DISCUSSIONS

#### AFTER EACH SUBTHEME SESSION:

- Open 30 minute DISCUSSION with audience and theme leader/speakers/panel
  - Questions and answers
  - Identification of additional technologies from audience
- Audience prioritization of critical technologies

#### JOINT THEME DISCUSSION, Thursday 8:30-10:45 am

- Discussion between audience and all theme element speakers
- Resolution of critical technologies across theme

### THEME SESSION OBJECTIVES

#### PURPOSE:

- Identify and prioritize in-space technologies for space structures by considering subtheme details which
  - are critical for future U. S. space programs.
  - require development and in-space validation.
- Generate comments and suggestions from aerospace community on OAST IN-STEP plans.

#### PRODUCT:

- Priority listing of critical space technology needs and associated space flight experiments, recommended by aerospace community.

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

Background and Objectives

*Theme Orientation and Recap of In-Space RT&E Workshop (Williamsburg, '85)*

Martin M. Mikulas, Jr.

NASA Langley Research Center, Hampton, Virginia

**Summary of**

**Space Structures Theme from  
1985 Williamsburg, VA In-Space RT&E Workshop**

**KEY STRUCTURES DYNAMICS  
AND CONTROL TECHNOLOGIES**

- 1. COMPONENT TECHNOLOGY**
  - SENSORS
  - ACTUATORS
- 2. CONTROL STRUCTURE INTERACTION**
  - CONTROL TECHNOLOGY
  - STATION KEEPING
  - MANUEVERS
  - POINTING
- 3. SPACE STATION DYNAMIC CHARACTERIZATION**
  - DYNAMIC MODELLING
- 4. SPACE STATION CONSTRUCTION TECHNOLOGY**
  - MATERIAL BEHAVIOR
  - ASSEMBLY
  - DEPLOYMENT
- 5. ADVANCED STRUCTURAL CONCEPTS**

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

Background and Objectives

*Theme Orientation and Recap of In-Space RT&E Workshop (Williamsburg, '85)*

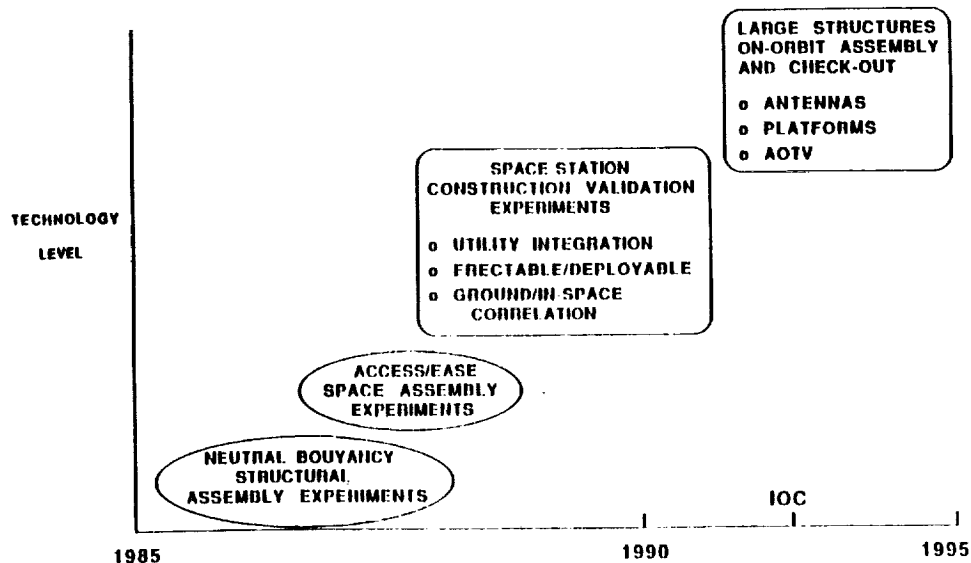
Martin M. Mikulas, Jr.

NASA Langley Research Center, Hampton, Virginia

### TECHNOLOGY GAPS IN PROPOSED EXPERIMENTS

- o VALIDATION OF STATION IOC CONSTRUCTION AND UTILITY INTEGRATION
- o VALIDATION OF LONG-TERM STRUCTURAL INTEGRITY
- o PASSIVE DAMPING
- o IN-SPACE LOADS CHARACTERIZATION
- o COST-EFFECTIVE HARDWARE DEVELOPMENT
- o STRUCTURALLY-EMBEDDED SENSORS/ACTUATORS
- o VIBRATION/SHAPE CONTROL DEVICES
  - SENSORS
  - ACTUATORS
- o LOW-FREQUENCY ISOLATION DEVICES

### SPACE CONSTRUCTION TECHNOLOGY



Theme 1 of 8

## SPACE STRUCTURES

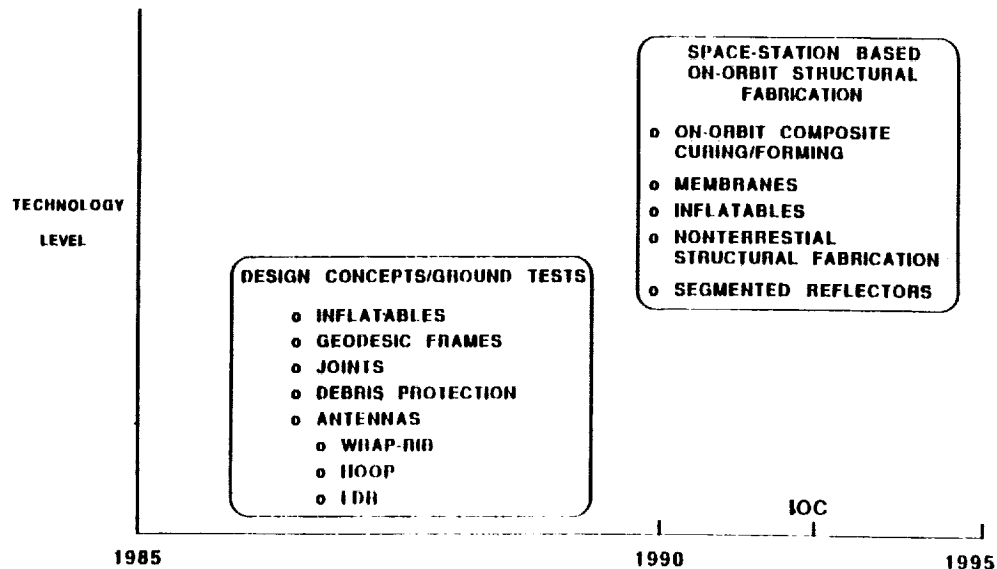
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Background and Objectives

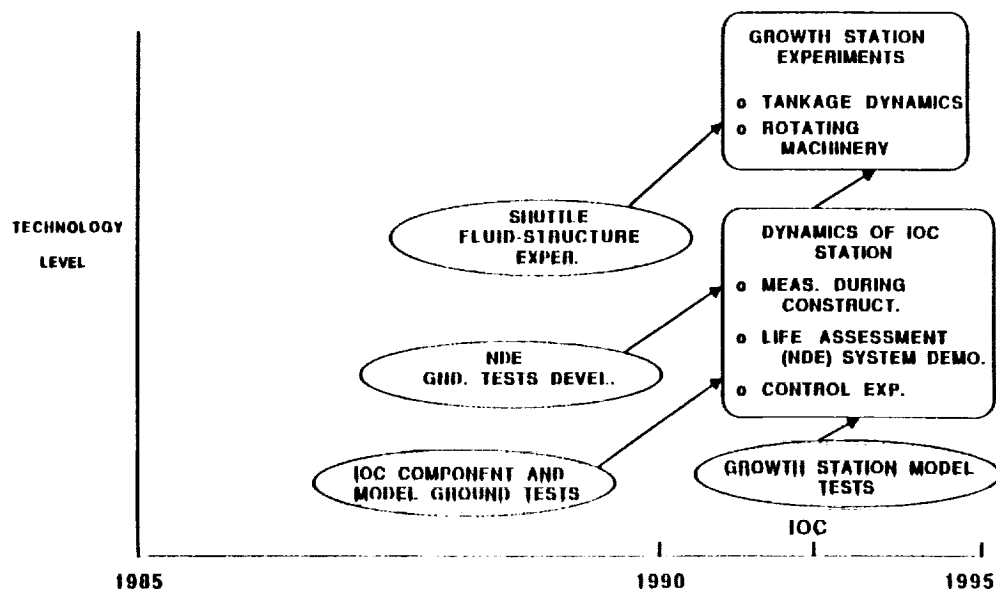
*Theme Orientation and Recap of In-Space RT&E Workshop (Williamsburg, '85)*

Martin M. Mikulas, Jr.  
NASA Langley Research Center, Hampton, Virginia

### ADVANCED STRUCTURAL CONCEPTS



### SPACE STATION DYNAMIC CHARACTERIZATION



Theme 1 of 8

## SPACE STRUCTURES

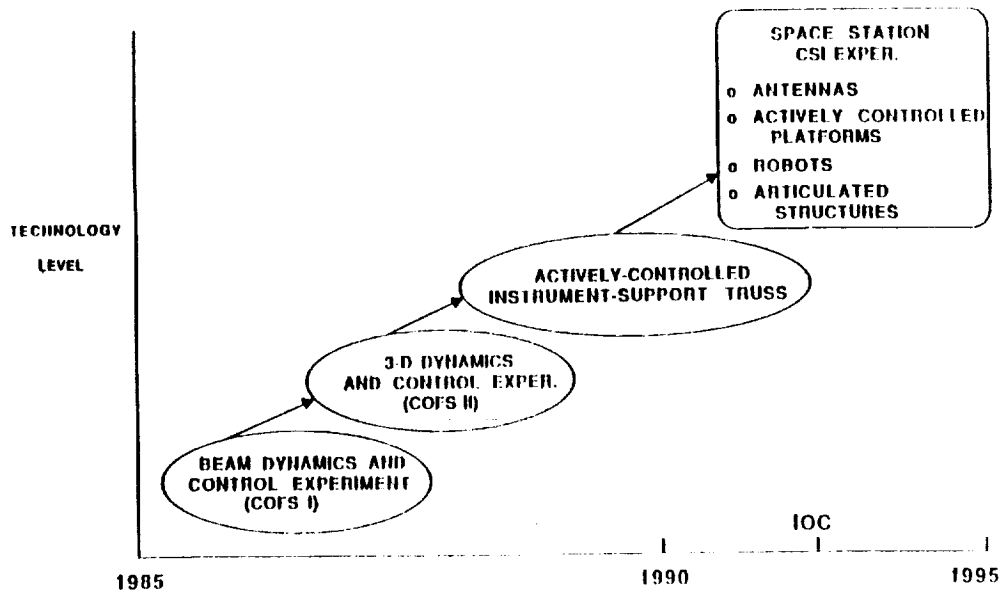
Background and Objectives

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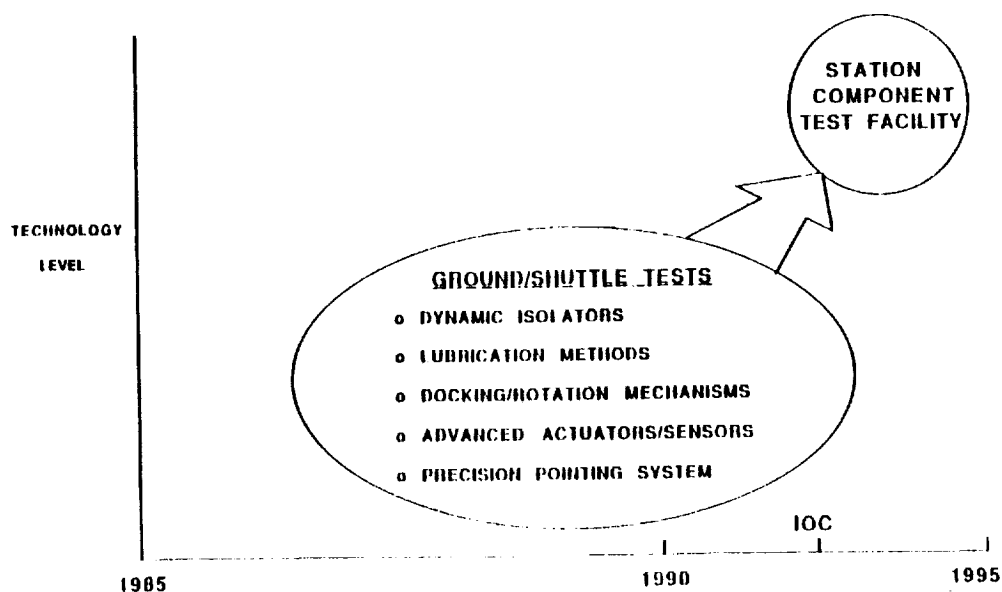
*Theme Orientation and Recap of In-Space RT&E Workshop (Williamsburg, '85)*

Martin M. Mikulas, Jr.  
NASA Langley Research Center, Hampton, Virginia

### CONTROL/STRUCTURES INTERACTION (CSI)



### COMPONENT TECHNOLOGY



Theme 1 of 8

**SPACE STRUCTURES**  
Background and Objectives

Theme 1 of 8

*Theme Orientation and Recap of In-Space RT&E Workshop (Williamsburg, '85)*

Martin M. Mikulas, Jr.  
NASA Langley Research Center, Hampton, Virginia

**CRITICAL ELEMENTS NEEDED FOR DEVELOPMENT**

- o HIGH ACCURACY SURFACE SENSOR (MULTI DOF)
- o REAL-TIME PHOTOGRAMETRIC CONCEPT
- o MID-RANGE MOMENTUM ACTUATORS
- o HIGH SPEED, HIGH CAPACITY FLIGHT COMPUTERS FOR CSI
- o HIGH SPEED, HIGH CAPACITY DATA BASES
- o MULTI-BODY ALIGNMENT TRANSFER & POINTING SYSTEM
- o RELATIVE ALIGNMENT SENSOR
- o VIBRATION ACTUATORS
- o LOW-FREQUENCY ACTUATORS
- o OPTICAL/INERTIAL VIBRATION SENSORS
- o LOW-G ACCELEROMETER
- o LOW-THRUSTER FOR REBOOST

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.1 Structures

#### *Air Force Structural Dynamics and CSI Technology Needs*

Jerome Pearson

Structural Dynamics Branch, Flight Dynamics Laboratory  
USAF Wright Aeronautical Laboratories

## INTRODUCTION/BACKGROUND

---

o PROPOSED SPACE SYSTEMS ARE VERY LARGE, AND INHERENTLY FLEXIBLE

- ADVANCED COMMUNICATIONS
- SPACE BASED RADAR
- SPACE STATION
- SDI SPACE BASED ARCHITECTURE

o MISSIONS CALL FOR EXTREMELY PRECISE ACQUISITION, SLEW, POINTING, TRACKING, AND FIGURE CONTROL

- MICRON DISPLACEMENT CONTROL
- NANORADIAN POINTING ACCURACIES
- AN EXTREME RETARGET CHALLENGE

o THE COMBINED IMPACT OF STRUCTURE, MISSION, AND ENVIRONMENT REQUIRES A SIGNIFICANT 'LEAP' BEYOND CURRENT CAPABILITIES.

## MISSION APPLICATIONS

---

o TECHNOLOGY NEEDS DRIVEN BY NUMEROUS SYSTEMS

### - NEAR TERM SYSTEMS

- SSTS/BSTS
- ADVANCED COMMUNICATIONS
- SPACE BASED RADAR

### - FAR TERM SYSTEMS

- SPACE BASED LASER
- RAIL GUN
- NPB

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.1 Structures

#### *Air Force Structural Dynamics and CSI Technology Needs*

Jerome Pearson

Structural Dynamics Branch, Flight Dynamics Laboratory  
USAF Wright Aeronautical Laboratories

## TECHNOLOGY NEEDS

---

- o PASSIVE DAMPING
  - PASSIVE DAMPING DESIGN CONCEPTS
  - PASSIVE DAMPING OPTIMIZATION
  - DAMPING MATERIALS CERTIFICATION FOR SPACE
- o ACTIVE CONTROL
  - HIGH EFFICIENCY, LOW MASS ACTUATORS
  - ACCURATE MULTI-POINT SENSORS
  - DISTRIBUTED SENSING/PROCESSING/ACTUATION
  - ULTRA PRECISION SENSORS/CONTROL LAWS/ACTUATORS
  - STRUCTURAL STIFFNESS/PASSIVE DAMPING/CONTROL OPTIMIZATION
- o GROUND TESTING
  - SYSTEM PARAMETER IDENTIFICATION
  - MICROGRAVITY SUSPENSION
  - ULTRA-PRECISION, LOW FREQUENCY MEASUREMENTS

## IN SPACE EXPERIMENTATION NEEDS/VOIDS

---

- o SPACE TESTING TO VERIFY GROUND DYNAMIC TEST RESULTS
- o ON-ORBIT SYSTEM IDENTIFICATION METHODS
- o SENSOR AND ACTUATOR BEHAVIOR IN THE SPACE ENVIRONMENT
- o LONG TERM SPACE EXPOSURE EFFECTS

## SUMMARY/RECOMMENDATIONS

---

- o ESTABLISH ZERO GRAVITY STRUCTURAL CHARACTERIZATION METHODS
- o QUALIFY STRUCTURAL AND DAMPING MATERIALS
- o QUANTIFY OPTIMAL TECHNOLOGY BLEND FOR VIBRATION SUPPRESSION
- o DEVELOP FREE FLYING STRUCTURAL DYNAMICS EXPERIMENT

Theme 11 of 18

## SPACE STRUCTURES

Theme 11 of 18

111 Structures

### Industry Perspective on Technology Needs for Space Structures

Donald E. Skourmal and Richard M. Gates  
Boeing Aerospace

## IN-SPACE INTRODUCTION / BACKGROUND / VOIDS

- Advanced structural concepts being defined
- Construction techniques
  - Large space structures will require on-orbit construction/assembly
  - Deployment
  - Assembly (manual, robotic)
  - Fabrication
  - Construction site/facility will impact concept design and assembly approach
  - Repair/maintenance
- Structural characterization techniques
  - Ground testing not always feasible
  - Quasi-static (as-built accuracy, thermal deflections)
  - Dynamic (mode shapes, frequencies, damping, non-linearities)
  - Large analytical models for in-space predictions
- Sensor/actuator technology
  - Testing must simulate actual environment
  - Embedded devices
  - New NDE methods coming along
  - Optical/laser measurement systems
- NDE methods for applications
  - In-space testing required
  - Structural characterization
  - Damage detection and isolation

- Space Station

## MISSION APPLICATIONS

## SUMMARY / RECOMMENDATIONS

Antennas  
Earth observation  
Need Cohesive Interdisciplinary Plan:  
Communications

- Innovative Precision reflectors
- LDR
- Compatible VLBI Instruction Approaches
- SBR
- Improved Ground Test Methods
  - Manned spacecraft
- In-Space Structural Characterization
  - Space Station
  - Manned Mars Mission
- Model Verification and Long Life Integrity through In-Space Technology Demonstrations

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.1 Structures

***Industry Perspective on Technology Needs for Space Structures***

Donald E. Skoumal and Richard M. Gates  
Boeing Aerospace

**TECHNOLOGY NEEDS**

- Structural concepts
  - Deployable
  - Erectable
- Construction techniques
  - Deployment
  - Manual assembly
  - Fabrication
- Structural characterization
  - As-built accuracy
  - Dynamic characteristics
- Ground test methods
  - Components/assemblies
  - Scaled models
- Analytical prediction techniques
  - Model fidelity
  - Multi-body issues
- Sensor/actuator technology
  - Embedded devices
  - Conventional
- Modular
- Smart structure
- Robotic assembly
- Repair/maintenance
- Health monitoring
- Measurement techniques
- Zero spring rate supports
- Nonlinear representations (joints, friction)
- Structure/wavefront interaction (CSI)

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.1 Structures

#### *Industry Perspective on Technology Needs for Space Structures*

Donald E. Skoumal and Richard M. Gates  
Boeing Aerospace

## IN-SPACE EXPERIMENTATION NEEDS / VOIDS

- Construction techniques
  - Deployment
  - Assembly (manual, robotic)
  - Fabrication
  - Repair/maintenance
- Structural characterization techniques
  - Quasi-static (as-built accuracy, thermal deflections)
  - Dynamic (mode shapes, frequencies, damping, non-linearities)
- Sensor/actuator technology verification
  - Embedded devices
  - Optical/laser measurement systems
- NDE methods for In-Space applications
  - Structural characterization
  - Damage detection and isolation
- Space Station Facility for Technology Demonstrations

## SUMMARY / RECOMMENDATIONS

Need Cohesive Interdisciplinary Plan:

- Innovative Structural Concepts
- Compatible Construction Approaches
- Improved Ground Test Methods
- In-Space Structural Characterization
- Model Verification and Long Life Integrity  
through In-Space Technology Demonstrations

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.1 Structures

***University Participation in In-Space Technology Experiments***

**K.C. Park**

University of Colorado, Center for Space Structures and Controls

**In-Space Experiments Criteria for University**

- **Maximum Student and Multi-Institution Participation**
- **Experiments That Lead to New Analytical Research**
- **Progressive Difficulty in Design and Instrumentation**
- **Experiments That Provide Real-World Experience and Will Be Adopted by NASA**
- **Multi-Disciplinary Features: Structure-Dynamics, Structure-Control, Structure-Robotics**

**Technology Needs for University Space Structures Program**

- **Structures Discipline:**
  - **In-Space Construction: Deployment/Assembly Simulation Validation**
  - **LSS Modeling and System Identification**
  - **Structural Modifications and Dynamic Stability**
  - **Design and Test of Fully Instrumented Structures**
  - **Joining/Assembly Design and Test Methods**

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.1 Structures

***University Participation in In-Space Technology Experiments***

**K.C. Park**

University of Colorado, Center for Space Structures and Controls

**Technology Needs for University Space Structures Program**

- **Structures-Other Discipline Fertilization:**
  - **Articulation and Maneuvering of Structures by Space Crane**
  - **Smart Structural Elements and Active Controls**
  - **Accurate Pointing of Flexible Manipulator Tip**
  - **Tether Retrieval and Retrieval Platform Dynamics**
  - **Thermal Transients and Shape Control**

**Candidate In-Space Experiment Needs  
for  
University Space Structures Program**

**Progressively Instrumented Space Crane**

- **Repetitive Usage for Several Experiments**
- **Long-Term Involvement of Students**
- **Interdisciplinary Activities (i.e., Controls, Dynamics, Robotics, Instrumentation)**
- **Models and Experimental Data Can Be Shared by Many Institutions**

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.1 Structures

#### *University Participation in In-Space Technology Experiments*

K.C. Park

University of Colorado, Center for Space Structures and Controls

#### **Candidate In-Space Experiment Needs for University Space Structures Program**

#### **Proposed Experiments for Scale-Model Space Crane**

Experiment	Description
#1	Ground Test of Assembly and Dynamics
#2	Motion Study of Assembly Procedures and Dynamics
#3	Re-Design of the Model Crane
#4	Articulation and Controls
#5	Environmental/Operational Loads Identification
#6	Full Instrumentation and Systems Integration
#7	Use of Space Crane for Construction Demands

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.2 Control/Structure Interaction (CSI)

***An Overview of the NASA Controls-Structures-Interaction Program***

J. Newsom, Langley Research Center  
H. Waites, Marshall Space Flight Center; W. Layman, Jet Propulsion Laboratory

**THE NASA CONTROLS-STRUCTURES  
INTERACTION (CSI) PROGRAM**

- A RESTRUCTURING OF THE COFS PROGRAM
- EMPHASIZES INCREASED GROUND TESTING AND ANALYTICAL METHODOLOGY DEVELOPMENT WITH A CONSERVATIVE FLIGHT EXPERIMENT SCHEDULE
- SPACECRAFT APPLICATIONS WEIGHTED TOWARD SCIENCE MISSIONS FOR THE 2000+ TIME FRAME
- JOINT EFFORT OF NASA HEADQUARTERS, LANGLEY, MARSHALL AND JPL

**CSI TECHNOLOGY NEEDS**

- QUANTIFICATION OF MISSION REQUIREMENTS AND BENEFIT TRADE-OFFS
- INTEGRATED MODELING, ANALYSIS, AND CONTROL/STRUCTURE DESIGN APPROACHES
- GROUND TEST METHODS FOR VERIFYING CSI DESIGNS
- SELECTED IN-SPACE FLIGHT EXPERIMENTS TO QUANTIFY ACCURACY OF GROUND-BASED PREDICTIONS

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.2 Control/Structure Interaction (CSI)

#### *An Overview of the NASA Controls-Structures-Interaction Program*

J. Newsom, Langley Research Center  
H. Waites, Marshall Space Flight Center; W. Layman, Jet Propulsion Laboratory

## IN-SPACE FLIGHT EXPERIMENT PLANNING

### APPROACH

- DEFINE CSI ELEMENTS REQUIRING FLIGHT TESTING ("NEEDS" ASSESSMENT)
- DEFINE APPROACHES FOR REDUCING FLIGHT EXPERIMENT COSTS (LOW-COST SYSTEMS STUDY)
- QUANTIFY TECHNOLOGY RETURN FROM CANDIDATE EXPERIMENT OPPORTUNITIES (POTENTIAL RETURN EVALUATIONS)

## FLIGHT EXPERIMENT PLANNING

### LOW-COST SYSTEMS STUDY

- TAKE ADVANTAGE OF EXPERIMENTAL NATURE---
  - SHORT DURATION
  - RETEST OPPORTUNITY
  - PREDICTABLE PERFORMANCE
  - INHERENT REDUNDANCY

### TO RELAX REQUIREMENTS AND REDUCE COST---

- OPERATING LIFE
- QUALITY CONTROL
- PERFORMANCE TOLERANCES
- RELIABILITY
- TRACEABILITY
- NOISE GENERATION

- TRADE:  
SHUTTLE-ATTACHED VS FREE FLYERS

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.2 Control/Structure Interaction (CSI)

***An Overview of the NASA Controls-Structures-Interaction Program***

J. Newsom, Langley Research Center  
H. Waites, Marshall Space Flight Center; W. Layman, Jet Propulsion Laboratory

**SUMMARY**

- CONTROLS-STRUCTURES INTERACTION (CSI) IS A KEY ENABLING TECHNOLOGY FOR FUTURE NASA SPACECRAFT
- PROPER IMPLEMENTATION OF CSI TECHNOLOGY PROMISES SIGNIFICANT IMPROVEMENTS IN CAPABILITY AT LESS COST
- CSI IS EFFECTIVELY A NEW DISCIPLINE WHICH ENCOMPASSES AND INTEGRALLY MERGES STRUCTURES AND CONTROLS
- NASA HAS EMBARKED ON A MAJOR MULTI-CENTER EFFORT TO DEVELOP THIS TECHNOLOGY FOR PRACTICAL APPLICATION IN SPACECRAFT
- A CONSERVATIVE FLIGHT EXPERIMENT APPROACH IS PLANNED
  - ON-ORBIT TEST WHEN READY AND NEED EXISTS
  - STUDY WAYS TO REDUCE FLIGHT EXPERIMENTS
  - STUDY ADVANTAGES/DISADVANTAGES OF SMALL-SCALE VS LARGE-SCALE FLIGHT EXPERIMENTS

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.2 Control/Structure Interaction (CSI)

#### *Technology Development Needs: Industry Perspective*

Carolyn S. Major  
TRW Space & Technology Group

## INTRODUCTION/BACKGROUND

- CSI technology motivated by many future missions
  - Large flexible structures
  - Precision pointing and agility
- Research in CSI dates to mid '70's
- Plethora of ground experiments (government, academia, industry)
- Several space experiments planned but thwarted (e.g., ACOSS, ACE, COFS)

## MISSION APPLICATIONS

Missions	Constituent Parts			
	Deployable Reflectors	Segmented Optics	Articulated Payloads	Flexible Appendages
SBL		X	X	
SBR	X		X	
EOS			X	X
VLBI			X	X
LDR	X	X		
SSTS			X	X
A-TDRS	X		X	X

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.2 Control/Structure Interaction (CSI)

#### *Technology Development Needs: Industry Perspective*

Carolyn S. Major  
TRW Space & Technology Group

#### TECHNOLOGY NEEDS

- Improved modeling
  - beyond NASTRAN
  - non-linear multibody dynamics
- On-line system identification and adaptive control
- Integrated controls/structures design approaches
- Coordinated control system design techniques: slew and point, active and passive
- Component development
  - embedded sensors & actuators
  - space qualified parallel processor
  - light-weight active isolators

#### IN-SPACE EXPERIMENTATION NEEDS/VOIDS

- Modeling, identification & components must be proven via space experimentation
- Design methodologies can be developed and proven with rigorous ground experiments

#### SUMMARY/RECOMMENDATIONS

- Piggy-back CSI hardware & software on appropriate near-term missions for cost-effective, timely validation
  - Vehicle accommodation of CSI equipment (weight, power, data handling)
  - Requirements for additional a priori testing
- Proceed with top-down ground experiment with well-defined mission requirements to further design methodologies

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.2 Control/Structure Interaction (CSI)

#### *The Need for Space Flight Experimentation in Control/Structure Interaction*

Edward F. Crawley

Massachusetts Institute of Technology

Department of Aeronautics & Astronautics, Space Engineering Research Center

## ARE THERE MISSIONS WHICH NEED CSI?

- Space Science -
  - Astronomical
  - Multi Payload Platforms
  - Planetary Exploration
  - Fundamental Physics
  - Micro Gravity
- Commercial/Transportation
  - Communications
  - Infra Structure
- Defense

## SERC APPROACH

Rather than examine specific missions, extract common configuration themes, and associated requirements

- Two point alignment (e.g., Masking instruments)
- Multipoint alignment (e.g., Interferometer)
- Precision surface control (e.g., Reflector, collector)
- Multi sensor isolation (e.g., Platforms)
- Multibody articulation (e.g., Planetary exploration)
- Micro gravity environment maintenance (e.g., Materials)
- Large system attitude stabilization (e.g., Physics)
- Other defense configurations
- Non space configurations

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.2 Control/Structure Interaction (CSI)

#### *The Need for Space Flight Experimentation in Control/Structure Interaction*

Edward F. Crawley

Massachusetts Institute of Technology

Department of Aeronautics & Astronautics, Space Engineering Research Center

## CLASSES OF TECHNOLOGY NEEDS

SERC has identified the following critical technology needs:

System Architecture

Structural Concepts

Control for Structures

Structures for Control

Hardware Development

Test and Verification

## SYSTEM ARCHITECTURE AND STRUCTURAL CONCEPTS

- System architecture -
  - Identify disturbance sources, transmission paths and performance critical locations
  - Minimize disturbances through selection of spacecraft systems and layout
- Structural concepts -
  - Develop precision construction or deployment techniques
  - Provide ability to reconfigure structure using mechanisms which carry static loads passively
  - Design for zero CTE, large size, long lifetime and low density

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.2 Control/Structure Interaction (CSI)

#### *The Need for Space Flight Experimentation in Control/Structure Interaction*

Edward F. Crawley

Massachusetts Institute of Technology

Department of Aeronautics & Astronautics, Space Engineering Research Center

## CONTROL FOR STRUCTURES AND STRUCTURES FOR CONTROL

- Control for structures
  - Hierarchic control
  - Control using intelligent materials
  - Actuator and sensor staging for enhanced dynamic range and bandwidth
  - Techniques based upon alternate modelling techniques
- Structures for control
  - Provide required passive damping
  - Provide frequency regimes for controller rolloff where modes are suppressed
  - Modeling of micro-dynamics

## HARDWARE DEVELOPMENT AND TEST AND VALIDATION

### Hardware development -

- Space-realizable sensors and actuators
- Spatially continuous sensors
- Dual function actuators/sensors
- Expand the numbers and types of available flight sensors, actuators and computers

### Test and validation -

- Provide the ground test program to which flight test data is to be correlated
- Identify unknowns and unmodelled aspects of plant
- Verify that control hardware and software is effective and robust

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.2 Control/Structure Interaction (CSI)

***The Need for Space Flight Experimentation in Control/Structure Interaction***

**Edward F. Crawley**

Massachusetts Institute of Technology  
Department of Aeronautics & Astronautics, Space Engineering Research Center

**THREE POTENTIAL ROLES OF  
CSI SPACE FLIGHT EXPERIMENTS**

- Investigation of basic technology, to understand a fundamental gravity dependence in the physics of the problem
- Demonstration of capabilities, to increase confidence in the maturity of CSI technology
- Development of a spacecraft qualification procedure, to be used in the "flight test" of future vehicles which use CSI technology

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.3 Controls

***Space Structures: Controls (Validation—Ground and In Space)***

Henry B. Waites  
NASA Marshall Space Flight Center

GENERAL PLAN

- o ANALYTICAL MODELING
- o HARDWARE TESTING
  - oo OPEN LOOP
    - EXCITATION
    - SENSORS
    - TELEMETRY
    - DATA REDUCTION
  - oo CLOSED LOOP
    - EXCITATION
    - SENSORS
    - TELEMETRY
    - DATA REDUCTION
- o VALIDATION
  - oo MODEL COMPARISON
  - oo MODEL CHANGES OR UPDATES
- o PROGRAMS
  - oo GROUND FACILITIES (MSFC)
    - SINGLE STRUCTURE (SS) LAB (CA, ASU, CRU, VCOSS-II, ACES I-IV)
    - MULTI-STRUCTURE (MS) LAB (CASES, POF, ASO, ASOR)
    - MULTI-BODY MODELING VERIFICATION AND CONTROL (MMVC) LAB
    - ROBOT ENHANCEMENT (RE) LAB
  - oo IN-FLIGHT
    - IPS
    - SAFE-I
    - CASES

ANALYTICAL MODELING

- o MASS
- o STIFFNESS
- o GEOMETRY
- o BOUNDARY CONDITIONS
- o SEISMIC AND SUSPENSION EFFECTS
- o NONLINEARITIES
- o METHODS

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

#### *Space Structures: Controls (Validation—Ground and In Space)*

Henry B. Waltes  
NASA Marshall Space Flight Center

#### HARDWARE TESTING

- o SUPPORT STRUCTURE
- o EXCITATION
  - oo BANDWIDTH AND OTHER LIMITS
  - oo INTERFACES (CONNECTIONS, CABLES, ETC.)
  - oo LOCATION(s)
  - oo CALIBRATION AND MONITORING
  - oo TELEMETRY
- o SENSORS
  - oo BANDWIDTH AND OTHER LIMITS
  - oo INTERFACES
  - oo LOCATION(s)
  - oo CALIBRATION AND MONITORING
  - oo TELEMETRY
- o OPEN LOOP
  - oo IMPACT OR IMPULSE
  - oo SINGLE AND MULTI-POINT RANDOM
  - oo SINE DWELL
  - oo SINE SWEEP
  - oo COHERENCE
  - oo LINEARITY
    - RECIPROCITY
    - EFFECTORS LEVELS
  - oo NONLINEARITY
    - IN-THE-LARGE
    - IN-THE-SMALL
  - oo EIGENVALUES AND EIGENVECTORS
- o CLOSED LOOP
  - oo TRANSFER FUNCTIONS
  - oo EIGENVALUES AND EIGENVECTORS
  - oo CONTROLS STRUCTURES INTERACTION

#### VALIDATION

- o MODEL(s) VS TEST CONFIGURATION(s)
- o MODEL CHANGES AND UPDATES
  - oo MASS
  - oo STIFFNESS
  - oo GEOMETRY
  - oo BOUNDARY CONDITIONS
  - oo SEISMIC AND SUSPENSION AFFECTS
  - oo DAMPING
- o UPDATED MODEL VS TEST CONFIGURATION
- o TRANSITION MODEL

#### EXAMPLES

- o SS LAB
- o IPS
- o SAFE-I
- o FUTURE PROGRAMS

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

#### *Industry Perspective on Control Technology Needs for Space Flight Verification*

Irving Hirsch  
Boeing Aerospace

## MISSION APPLICATIONS

Class/Example	Typical Issues
<ul style="list-style-type: none"> <li>• Large flexible spacecraft</li> <li>• Large deployable reflector</li> <li>• Very large optical Interferometer</li> </ul>	<ul style="list-style-type: none"> <li>• Space assembly (handling/robotics)</li> <li>• Jitter control/precision pointing/shape control</li> </ul>
<ul style="list-style-type: none"> <li>• Manned spacecraft</li> <li>• Space station</li> <li>• Manned Mars mission</li> </ul>	<ul style="list-style-type: none"> <li>• System Identification</li> <li>• Precision appendage articulation</li> <li>• Space assembly (handling/robotics)</li> </ul>
<ul style="list-style-type: none"> <li>• Planetary exploration</li> <li>• Mars sample return mission</li> </ul>	<ul style="list-style-type: none"> <li>• Smart autonomy</li> <li>• Robustness</li> <li>• Precision appendage articulation</li> </ul>
<ul style="list-style-type: none"> <li>• Earth observation</li> <li>• Satellites</li> <li>• Tethers</li> </ul>	<ul style="list-style-type: none"> <li>• Precision appendage articulation</li> <li>• Stability/robustness</li> </ul>
<ul style="list-style-type: none"> <li>• Space transportation vehicles</li> <li>• Advanced Launch System</li> <li>• Shuttle C</li> <li>• Orbital transfer vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• Robustness</li> <li>• Adaptive control and estimation</li> <li>TVC actuation</li> </ul>

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

#### *Industry Perspective on Control Technology Needs for Space Flight Verification*

Irving Hirsch  
Boeing Aerospace

### TECHNOLOGY NEEDS

- **Modeling and simulation**
  - Accurate structural representations within control bandpass
  - Fluid flow interactions
  - Nonlinear joint response characterization
  - Realistic nonlinear controls component models
  - Accurate large-angle and slewing motion representations for flexible structures
  - Accurate translational connection representations for maneuvering and docking or grappleing
- **Controls algorithms**
  - Hierarchical and distributed control architectures
  - Application of robust and/or adaptive control theory
  - Nonlinear control methodology
  - Software redundancy for failure detection, isolation and reconfiguration of multiple sensors/actuators
  - Parallel processing (e.g., neural networks)
- **Controls components**
  - Magnetic suspension control moment gyros (CMG's)
  - Throttleable thrusters for proportional control
  - 'Smart' structures (i.e., embedded actuators/sensors)
  - Wavefront, surface shape, and alignment sensors
  - Fault-tolerant digital computers and interfaces
  - Low-g accelerometers
  - Low cost, low weight components
  - Passive damping elements
  - Electro mechanical actuators with redundancy
- **Design and analysis tools**
  - Common database executive and interface programs
  - Integrated system analysis and design optimization
- **Verification simulation and test**
  - Large-scale hardware-in-loop (HIL) simulators
  - Soft and air-bearing suspensions for large systems
  - Magnetic suspension for precision pointing and vibration isolation (in-space?)
  - Vision and force control test capability for robotics (in-space?)
  - Surface shape and wavefront control test capability (in-space?)

INSTEP88 Workshop OAST Technology For the Future Part 2: Critical Technologies	INSTEP Technology Themes
Theme 1 of 8	<div> <div> <b>SPACE STRUCTURES</b>            1.3 Controls  <i>Industry Perspective on Control Technology Needs for Space Flight Verification</i>            Irving Hirsch            Boeing Aerospace         </div> <div>           Theme 1 of 8         </div> </div>
<div> <div> <b>IN-SPACE EXPERIMENTATION NEEDS/VOIDS</b> </div> <div> <ul style="list-style-type: none"> <li>• Instrument and system identification of 'planned' spacecraft to quantify structural dynamics and correlate with ground test results (e.g., 'high frequency' space station modes and damping)               <ul style="list-style-type: none"> <li>• Joints unloaded in space</li> <li>• Micro-g environment</li> </ul> </li> <li>• Robotics assisted structural assembly               <ul style="list-style-type: none"> <li>• Astronaut interfaces</li> </ul> </li> <li>• Precision articulation/vibration isolation               <ul style="list-style-type: none"> <li>• Control hardware nonlinearities</li> <li>• Micro-g environment</li> </ul> </li> <li>• Advanced component technology verification               <ul style="list-style-type: none"> <li>• Non-ground testable</li> </ul> </li> </ul> </div> </div>	
<div> <div> <b>SUMMARY/RECOMMENDATIONS</b> </div> <div> <ul style="list-style-type: none"> <li>• Control Technology gaps exist for space flight verification</li> <li>• Many of these gaps can be cost effectively reduced by analysis, simulation and ground test</li> <li>• Some in-flight test verification is still required</li> <li>• Technology gaps in other subthemes overlap control technology gaps</li> <li>• A detailed space flight verification plan is required for integration with other subthemes</li> </ul> </div> </div>	

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

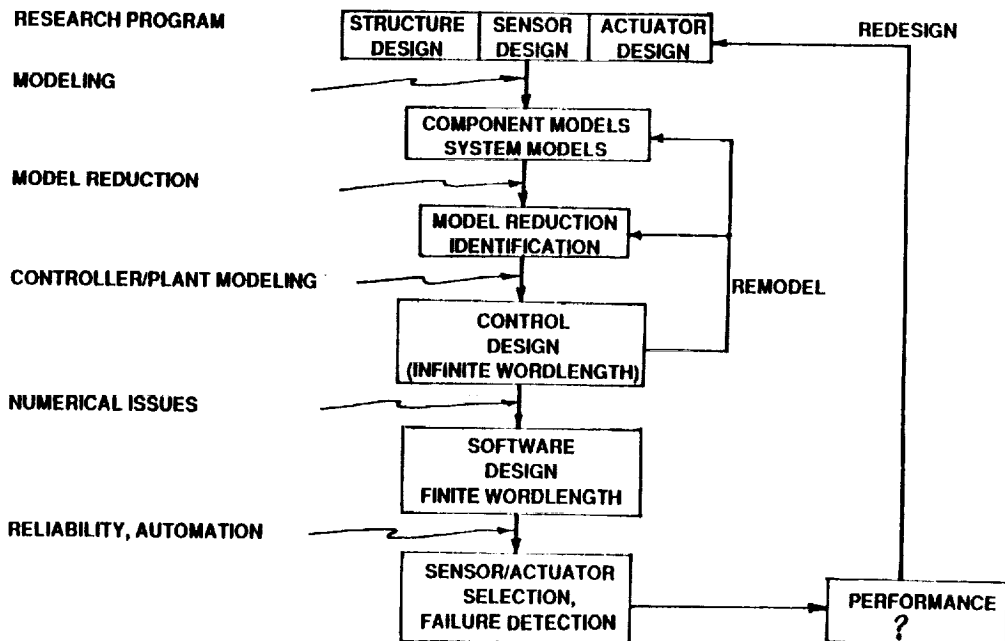
#### *Experiments in Dynamics and Controls*

Robert E. Skelton

Purdue University, School of Aeronautics & Astronautics

## INTRODUCTION / BACKGROUND

- LESSONS FROM THE PAST
- GUIDING PRINCIPLES
- THEORY NEEDS
- SOFTWARE NEEDS
- HARDWARE NEEDS
- THEME PROBLEMS, EXPERIMENTS



Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.3 Controls

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**THEORY NEEDS**

- **MULTIPLE PERFORMANCE GUARANTEES**
- **ROBUSTNESS GUARANTEES**
- **NUMERICAL ISSUES IMBEDDED IN CONTROLLER DESIGN**
- **THEORY OF DESIGN INTERACTIONS  
(CONVERGENCE)**
- **IMPACT ON HARDWARE COMPONENT DESIGN  
(SUBSYSTEM SPECS FROM SYSTEM GOERS)**

**SOFTWARE NEEDS**

- **DESIGN WORKSTATIONS  
(FOR FAST DESIGN ITERATIONS)  
(GRAPHIC PRESENTATION OF TRADEOFFS)**
- **OPTIMIZING SIMULATIONS FOR MAXIMAL ACCURACY  
COMPUTATIONS**
- **OPTIMIZING CONTROLLER SOFTWARE FOR MAXIMAL ACCURACY  
COMPUTATIONS**
- **OPTIMAL TRADEOFFS BETWEEN HARDWARE/SOFTWARE IN  
SIMULATIONS AND LAB EXPERIMENTS**

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

#### *Experiments in Dynamics and Controls*

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## HARDWARE NEEDS

- **NEW SENSORS**  
OPTIMAL NOISE LEVELS (FROM COMPONENT SPECS)  
POSITION, RATE, ACCELERATION, STRAIN  
DISTRIBUTED, RELIABLE, HARDENED
- **NEW ACTUATORS**  
OPTIMAL NOISE LEVELS (FROM COMPONENT SPECS)  
CURRENT, VOLTAGE, TORQUE, MOMENTUM EXCHANGE,  
MASS DISTRIBUTION,
- **NEW COMPUTERS TAILORED TO FLIGHT CONTROL NEEDS**  
PARALLEL PROCESSING?  
MULTIPLE WORD LENGTH & SAMPLE RATES?
- **NEW LAB EXPERIMENTS TO TRADEOFF DESIGN METHODOLOGIES**

## THEME PROBLEMS

- **NEEDED AT EVERY LEVEL.**
  - **ANALYTICAL EXPERIMENTS**
    - PDE VS ODE
    - MODEL REDUCTION
    - CONTROL DESIGNS
  - **NUMERICAL EXPERIMENTS SIMULATION**
    - IDENTIFICATION IN CLOSED LOOP
    - ADAPTIVE CONTROLLERS
    - ROBUST CONTROLLERS
    - N-BODY GENERATION PROGRAMS
  - **HARDWARE EXPERIMENTS**
    - ACTUATORS
    - SENSORS
    - CLOSED LOOP

Theme 1 of 8

**SPACE STRUCTURES**

Theme 1 of 8

1.3 Controls

***Experiments in Dynamics and Controls***

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**SUMMARY/RECOMMENDATIONS**

- **DEVELOP FLEXIBLE STRUCTURE THEME PROBLEMS AT 3 LEVELS:**
  - **ANALYTICAL EXPERIMENTS**
  - **NUMERICAL EXPERIMENTS**
  - **HARDWARE EXPERIMENTS (LAB, FLIGHT)**
- **TO TEST**
  - **MODELING FOR CONTROL DESIGN**
  - **CLOSED LOOP IDENTIFICATION AND CONTROL REDESIGN**
  - **SENSOR/ACTUATOR DESIGN, CONFIGURATION**
  - **COMPUTATIONAL ISSUES**
    - **WORDLENGTH**
    - **ACHITECTURE (PARALLEL, ARRAY, ETC.)**
    - **DECENTRALIZED COMPUTING**

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

#### *Space Structures Critical Technology Requirements*

Martin Mikulas, Jr.  
NASA Langley Research Center

### OBSERVATION

#### o PEOPLE ARE ASKING FOR

- MULTIDISCIPLINARY EXPERIMENTS
- REUSABLE TEST BEDS

#### o POTENTIAL TEST BEDS

- SPACE STATION
- PSR - SHUTTLE BASED
- ?

### SPACE EXPERIMENT TECHNOLOGY NEEDS AREAS (STRUCTURES, DYNAMICS, AND CONTROLS)

- CONTROL / STRUCTURES INTERACTION EXPERIMENTS
- STRUCTURAL CHARACTERIZATION EXPERIMENTS
- IN-SPACE CONSTRUCTION EXPERIMENTS

### CSI/SYSTEMS TECHNOLOGY NEEDS

	NEEDED EXPERIMENTS	
	FOR FUND. TECH. DEV.	FOR DEMO. OF TECH MATURITY
FLEXIBLE MULTI-BODY / ARTICULATED CONTROL	SPACE	SPACE
PRECISION POINTING AND SHAPE DIMENSIONAL CONTROL	SPACE	SPACE
MULTIPLE INTERACTING CONTROL SYSTEM	SPACE (?)	SPACE
DAMPING AND VIBRATION SUPPRESSION	GROUND	SPACE (?)
VIBRATION ISOLATION	GROUND	SPACE (?)
ACTIVE BALANCING	GROUND	GROUND

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

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## CSI / COMPONENTS

### TECH ISSUES

#### ◦ ACTUATORS, SENSORS AND PROCESSORS

- SHOULD ONLY BE TESTED IN SPACE AS AN INDIVIDUAL COMPONENT WHEN FUNDAMENTAL CHANGES IN CHARACTERISTICS ARE EXPECTED IN SPACE (E.G., RADIATION ON A COMPUTOR, GRAVITY ON AN INERTIAL SENSOR)

- OTHERWISE SHOULD ONLY BE TESTED IN SPACE AS PART OF A SYSTEM

### CRITERIA FOR SELECTING AN EXPERIMENT FOR SPACE TESTING

#### ◦ BASIC PRINCIPLE

- SPACE TESTING IS JUSTIFIED FOR FUNDAMENTAL TECHNICAL DEVELOPMENT ONLY IF THE EXPERIMENT CANNOT BE CONDUCTED ON EARTH OR WILL PRODUCE DISTORTED AND UNCORRECTABLE DATA WHEN CONDUCTED ON EARTH.

#### ◦ APPLIED TO CSI

- MIS-MODELING OF STRUCTURES AND "ZERO-G" SUSPENSIONS CAN MASK SINGULARITIES IN THE CONTROL / STRUCTURE SYSTEM WHICH CAN BE EVIDENCED ON-ORBIT BY SYSTEM INSTABILITY.
- THERE IS NO WAY OF GUARANTEEING THRU ON-ORBIT OPEN LOOP TESTING OR GROUND BASED CLOSED LOOP TESTING THAT THE SYSTEM WILL BE STABLE ON ORBIT AT DESIGN GAIN LEVELS.

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**SPACE STRUCTURES**

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**STRUCTURAL CHARACTERIZATION**  
**TECHNOLOGY NEEDS**

- o **SYSTEM IDENTIFICATION**
  - QUASI-STATIC
    - o AS-BUILT
    - o THERMAL DEFORMATIONS
  - DYNAMIC (OPEN LOOP AND CLOSED LOOP)
    - o STRUCTURAL DYNAMICS
    - o FLUID / STRUCTURE (SLOSH, FLOW)
  - DISTURBANCE SOURCE IDENTIFICATION
- o **SENSOR DEVELOPMENT**
  - PRECISION DYNAMICS DUE TO LOW LEVEL EXCITATION
  - STATIC SHARE SENSORS
  - DISTURBANCE QUALIFICATION
- o **VERIFICATION OF PREDICTION METHODS**
  - SCALE MODELS
  - COMPONENT GROUND TESTING
  - ANALYSIS
- o **STRUCTURAL INTEGRITY**
  - HEALTH MONITORING
  - NDE

Theme 1 of 8

**SPACE STRUCTURES**

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1.3 Controls

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**STRUCTURAL CHARACTERIZATION  
IN-SPACE EXPERIMENT JUSTIFICATION**

- o **ELIMINATES GROUND TEST LIMITATIONS**
  - o GRAVITY EFFECTS
  - o SUSPENSION SYSTEMS
  - o SIZE LIMITATIONS
  - o TERRESTRIAL DISTURBANCES THAT MASK THE PHYSICS
  - o
- o **ALLOWS SMALL SCALE EFFECTS TO BE IDENTIFIED**
  - o DAMPING
  - o NONLINEARITIES
  - o SENSOR CHARACTERISTICS
- o **PROVIDES REALISTIC TEST RESULTS FOR ANALYSIS  
VERIFICATION**

**IN-SPACE CONSTRUCTION EXPERIMENTS  
(TECHNOLOGIES CONSIDERED)**

- o **DEPLOYABLE STRUCTURES**
  - LARGE TRUSSES (SPACE STATIONS SIZE)
  - 10 - 15 METER HARD SURFACE REFLECTORS
  - 40 METER HARD SURFACE REFLECTORS
  - 55 METER MESH ANTENNAS
  - INFLATABLES (15-30 METERS)
- o **ERECTABLE STRUCTURES**
  - SPACE STATION
  - PRECISION SEGMENTED REFLECTOR (EVA ON SHUTTLE)
  - PRECISION SEGMENTED REFLECTOR (ROBOTIC / EVA)
- o **MAINTENANCE AND REPAIR**

Theme 1 of 8

## SPACE STRUCTURES

Theme 1 of 8

### 1.3 Controls

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### **TEST BED OBJECTIVE**

- o DEVELOP TECHNOLOGY ENABLING THE CONSTRUCTION AND OPERATION OF FUTURE SPACE CRAFT

### **APPROACH**

- o EVOLUTIONARY TESTBED
  - EACH PHASE IS A FRACTION OF THE COST
  - NEW TECHNOLOGY CAN BE ADDED MIDSTREAM
- o MULTIDISCIPLINARY TESTBED
  - LOOK AT ALL INTERESTED ASPECTS
  - MAXIMIZE BENEFIT / MONEY
  - PROVIDE RELEVANT SCIENCE FOCUS

### **PSR FLIGHT CONSTRUCTION EXPERIMENT PHASE I TASKS (STS PAYLOAD BAY)**

- CONSTRUCTION / ASSEMBLY
  - TRUSS
  - SIMULATED MIRROR SEGMENTS
  - UTILITIES (SENSORS AND WIRING)
- TIMELINE VERIFICATION
  - ZERO-G VS. NEUTRAL BUOYANCY
- AS-BUILT ACCURACY VERIFICATION
  - SURFACE
  - SUBSTRUCTURE
- HUMAN FACTORS VERIFICATION
  - CREW RESTRAINTS
  - LIGHTING (VIEW FACTORS)
  - TOOLS AND ASSEMBLY AIDS
- DYNAMIC CHARACTERIZATION

Theme 1 of 8

**SPACE STRUCTURES**

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**PHASE II TASKS (FREE-FLYER)**

- o SECOND ASSEMBLY TEST, FREE-FLYER
- o MAINTENANCE OF LONG TERM PASSIVE PRECISION
- o DISTURBANCE CHARACTERIZATION
- o DEGRADATION OF MATERIALS
- o RELIABILITY OF MEASUREMENTS

**PHASE III TASKS (REVISIT)**

- o REPAIRING, INSPECTION, CLEANING,  
SERVICING (ROBOTICS)
- o UPGRADING WITH
  - QUASI-STATIC RECONFIGURATION CAPABILITY
  - FURTHER UTILITIES (COOLANTS, FLUIDS, ETC)
  - PUMPS
  - VIBRATION ISOLATION

**FURTHER PHASE TASKS**

- o PHASED INCREASE IN CSI COMPLEXITY LEADING  
TO FUNCTIONAL SPACE SCIENCE INSTRUMENT

Theme 1 of 8

**SPACE STRUCTURES**

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1.3 Controls

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**PSR FLIGHT EXPERIMENT TEST BED  
MULTIDISCIPLINARY INVOLVEMENT**

	PHASE I				PHASE II	PHASE III	FURTHER PHASES
	TIMELINE	ACCURACY	HUMAN	CHARACTER			
<b>TECHNOLOGY THEMES</b>							
STRUCTURE	X	X		X	X	X	X
CSI						X	X
ROBOTICS						X	X
POWER & THERMAL						X	X
MAINTENANCE & REPAIR			X		X	X	X
HUMANS	X		X		X	X	X
ENVIRONMENT					X	X	X
FLUIDS						X	X
SENSORS		X		X	X	X	X
<b>USERS</b>							
OBSERVATORIES							X
MATERIAL DEVELOP.		X		X	X	X	X
PHYSICS				X	X	X	X

• SET SPECIFICATION  
X RECEIVE DATA

INSTEP88 Workshop OAST Technology For the Future Part 2: Critical Technologies		INSTEP Technology Themes
Theme 2 of 8	<b>SPACE ENVIRONMENTAL EFFECTS</b> Background and Objectives <i>Theme General Content and Sub-Theme Definition</i>  Lubert J. Leger NASA Johnson Space Center	Theme 1 of 8
<b>THEME SESSION OBJECTIVES</b> <ul style="list-style-type: none"> <li>● <b>PURPOSE</b> <ul style="list-style-type: none"> <li>● <b>IDENTIFY &amp; PRIORITIZE IN-SPACE TECHNOLOGIES FOR EACH THEME WHICH:</b> <ul style="list-style-type: none"> <li>- <b>ARE CRITICAL FOR FUTURE NATIONAL SPACE PROGRAMS</b></li> <li>- <b>REQUIRE DEVELOPMENT &amp; IN-SPACE VALIDATION</b></li> </ul> </li> <li>● <b>OBTAIN AEROSPACE COMMUNITY COMMENTS &amp; SUGGESTIONS ON OAST IN-STEP PLANS</b></li> </ul> </li> <li>● <b>PRODUCT</b> <ul style="list-style-type: none"> <li>● <b>AEROSPACE COMMUNITY RECOMMENDED PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS &amp; ASSOCIATED SPACE FLIGHT EXPERIMENTS</b></li> </ul> </li> </ul>		
<b>SPACE ENVIRONMENTAL EFFECTS THEME GENERAL CONTENT</b> <ul style="list-style-type: none"> <li>● <b>THEME ADDRESS ALL ENVIRONMENTAL EFFECTS ON SPACECRAFT SYSTEMS</b> <ul style="list-style-type: none"> <li>● <b>NEUTRAL AND CHARGED PORTION OF ENVIRONMENT</b></li> <li>● <b>INDUCED REACTIONS/INTERACTIONS LEADING TO SURFACE, ENVIRONMENT, EQUIPMENT CHANGES</b></li> <li>● <b>MICROMETEOROID/DEBRIS IMPACTS</b></li> <li>● <b>ELECTROMAGNETIC RADIATION</b></li> <li>● <b>CONTAMINATION</b></li> </ul> </li> <li>● <b>ALL ORBIT ALTITUDES AND INCLINATIONS CONSIDERED</b></li> <li>● <b>EXPERIMENTS LAUNCHED ON SPACE SHUTTLE, UNMANNED LAUNCH VEHICLES, FREE FLYERS AND CONDUCTED ON SPACE STATION</b></li> </ul>		

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

Background and Objectives

***Theme General Content and Sub-Theme Definition***

Lubert J. Leger  
NASA Johnson Space Center

**ENVIRONMENTAL EFFECTS SUB-THEME DEFINITION**

● **SUB-THEME 1 : ATMOSPHERIC EFFECTS AND CONTAMINATION**

- **ATOMIC OXYGEN EFFECTS**
- **LOCAL CHEMISTRY MODIFICATION**
- **PRESSURE EFFECTS**
- **DEPOSITION ON SURFACES**
- **PLUME AND VENT CONTAMINANTS**
- **SENSOR DEVELOPMENT**
- **CONTROL TECHNIQUES**
- **MEASUREMENT TECHNIQUES**

● **SUB-THEME 2 : MICROMETEORIDS AND DEBRIS**

- **SHIELD SYSTEMS**
- **ENVIRONMENT DEFINITION**
- **EFFECTS ON SPACECRAFT**
- **DETECTION AND IMPACT CONTROL**

● **SUB-THEME 3 : CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS**

- **ELECTRONIC SYSTEM EFFECTS**
- **MATERIAL DAMAGE**
- **SENSOR DEVELOPMENT**
- **PROTECTION SYSTEMS**
- **EMI / EMC**
- **SINGLE EVENT UPSET**
- **DOSAGE EFFECTS**
- **CHARGING**
- **PLASMA INTERACTIONS**

INSTEP88 Workshop OAST Technology For the Future Part 2: Critical Technologies		INSTEP Technology Themes
Theme 2 of 8	<b>SPACE ENVIRONMENTAL EFFECTS</b> Background and Objectives <i>Theme General Content and Sub-Theme Definition</i>  Lubert J. Leger NASA Johnson Space Center	Theme 1 of 8
<b>PRIORITIZATION CRITERIA*</b>  1.) <b>CRITICAL ENABLING TECHNOLOGIES</b> <ul style="list-style-type: none"><li>• <b>TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U. S. SPACE MISSIONS</b></li></ul> 2.) <b>COST REDUCTION TECHNOLOGIES</b> <ul style="list-style-type: none"><li>• <b>TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY (e.g., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)</b></li></ul> 3.) <b>BROAD APPLICATION TECHNOLOGIES</b> <ul style="list-style-type: none"><li>• <b>TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS</b></li></ul> 4.) <b>REQUIRE IN-SPACE VALIDATION</b> <ul style="list-style-type: none"><li>• <b>TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR VALIDATION OR EXPERIMENTATION</b></li></ul> * <b>CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1. = HIGHEST)</b>		
<b>THEME SESSION AGENDA</b>  • <b>THEME ELEMENT SESSIONS</b> <ul style="list-style-type: none"><li>• <b>CRITICAL SPACE TECHNOLOGY NEEDS FOR THEME ELEMENT FROM PERSPECTIVE OF:</b><ul style="list-style-type: none"><li>- <b>INDUSTRY, UNIVERSITIES &amp; GOVERNMENT</b></li></ul></li><li>• <b>OPEN DISCUSSION WITH THE AUDIENCE &amp; THEME ELEMENT SPEAKERS / THEME LEADER</b><ul style="list-style-type: none"><li>- <b>QUESTION &amp; ANSWER WITH SPEAKERS</b></li><li>- <b>IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE</b></li></ul></li></ul> • <b>COMBINATION &amp; PRIORITIZATION OF THEME TECHNOLOGIES</b> <ul style="list-style-type: none"><li>• <b>DISCUSSION BETWEEN AUDIENCE &amp; ALL THEME ELEMENT SPEAKERS</b></li><li>• <b>RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME</b></li></ul>		

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

**2.1 Atmospheric Effects and Contamination**

***Atmospheric Effects & Contamination: Government Perspective***

**Bruce A. Banks**  
NASA Lewis Research Center

BACKGROUND

- 0 Flight data from STS-3, -4, -5, -8, -41G and Solar Max
- 0 Most atomic oxygen does not react upon first impact
- 0 Lower reaction probabilities at near grazing incidence
- 0 Erosion yields for approximately 60 materials measured from flight tests with significant uncertainty for key materials
- 0 Materials which produce volatile oxidation products develop texture
- 0 Optical properties change ( $\alpha_s$ ,  $\epsilon$ ) observed
- 0 Basic atomic oxygen interaction processes and degradation pathways have been proposed but not fully verified
- 0 Influence of temperature and solar radiation on erosion yield has not been clearly determined

MISSION APPLICATIONS

- 0 Atomic oxygen durable materials must be identified for long duration LEO missions
- 0 Scattered atomic oxygen may threaten durability of materials on spacecraft interior
- 0 Erosion yields at low fluxes may allow use of some materials considered unacceptable at high fluxes
- 0 Atomic oxygen interactions must be understood in functional environment
  - Temperature
  - UV
  - Wandering or ram attack
- 0 Protective coating environmental durability is required for high performance spacecraft materials and surfaces

INSTEP88 Workshop OAST Technology For the Future Part 2: Critical Technologies		INSTEP Technology Themes
Theme 2 of 8	<b>SPACE ENVIRONMENTAL EFFECTS</b> 2.1 Atmospheric Effects and Contamination <i>Atmospheric Effects &amp; Contamination: Government Perspective</i>  <b>Bruce A. Banks</b> NASA Lewis Research Center	Theme 1 of 8
<u>TECHNOLOGY NEEDS</u> 0 Erosion yield dependence upon: <ul style="list-style-type: none"><li>- Flux</li><li>- Fluence</li><li>- Temperature</li><li>- Solar radiation</li></ul> 0 Scattered atomic oxygen reaction data 0 Higher certainty data for low erosion yield materials 0 Protective coating performance data <ul style="list-style-type: none"><li>- Undercutting oxidation at pinholes, cracks, and scratches</li><li>- Diffusion</li><li>- Functional performance</li></ul> 0 Adequate flight data to develop algorithms to predict flight performance from ground laboratory LEO simulation		
<u>IN-SPACE EXPERIMENT NEEDS/VOIDS</u> 0 Temperature dependency over broad range <ul style="list-style-type: none"><li>- Metals</li><li>- Polymers</li></ul> 0 Accurate flux/fluence measurements 0 High fluence data $10^{22}$ - $10^{23}$ atoms/cm <sup>3</sup> <ul style="list-style-type: none"><li>- Low erosion yield materials</li><li>- Protected coatings</li><li>- Evaluation of solar radiation dependence</li></ul> 0 Temporal erosion/reaction data 0 Scattered atomic oxygen erosion yield data 0 Functional performance evaluation of exposed materials <ul style="list-style-type: none"><li>- Protected or durable polymer films for solar arrays and thermal blankets</li><li>- Radiator surfaces</li><li>- Solar concentrators</li><li>- Structures</li><li>- Lubricants</li></ul>		

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

**2.1 Atmospheric Effects and Contamination**

***Atmospheric Effects & Contamination: Government Perspective***

**Bruce A. Banks**  
NASA Lewis Research Center

SUMMARY/RECOMMENDATIONS

- 0 Active experiments to allow erosion yield or reaction data to be taken under variable conditions of:
  - Flux
  - Fluence
  - Angle of attack
  - Temperature
  - Solar radiation
- 0 Scattered atomic oxygen erosion yield data
- 0 Active flux measurement
- 0 Functional evaluation of materials performance
  - Mechanical
  - Optical
  - Thermal radiative
  - Tribological
- 0 Adequate testing at low altitudes to develop high fluence ( $10^{22}$  -  $10^{23}$  atoms/cm<sup>2</sup>)

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

2.1 Atmospheric Effects and Contamination

***Atmospheric Effects & Contamination Technology Development Needs***

Lyle E. Bareiss

Martin Marietta Space Systems Company, Astronautics Group

**INTRODUCTION/BACKGROUND**

- CONTAMINATION DEFINED AS THE TRANSPORT OF MOLECULAR OR PARTICULATE MATERIAL TO UNDERSIRABLE LOCATIONS
- INDUCED ENVIRONMENT IN THE NEAR VICINITY OF SPACECRAFT WILL CAUSE SYSTEM/INSTRUMENT DEGRADATION
- TECHNOLOGY BASE IS INCOMPLETE AND FRAGMENTED THROUGHOUT INDUSTRY
- DEVELOPMENT OF CONTAMINANT FREE SPACE VEHICLE IS NOT CURRENTLY POSSIBLE
- FUTURE LONG TERM (10-30 YR) MISSIONS AND MORE SENSITIVE INSTRUMENTS WILL DICTATE THE NEED FOR ENHANCED UNDERSTANDING/TECHNOLOGY ADVANCES

**TECHNOLOGY NEEDS**

- LONG TERM CONTAMINANT SOURCE CHARACTERISTICS
  - $\dot{m} = f(T, t)$ , SPECIES, STICKING
- LONG TERM DEPOSITION EFFECTS DATA
  - COMBINED ENVIRONMENT EFFECTS
- ENHANCED COMPUTER MODELING CAPABILITIES
- CONTAMINATION REMOVAL METHODS/PREVENTION TECHNIQUES
- HIGH SENSITIVITY CONTAMINATION MONITORS
  - DEPOSITION
  - OPTICAL (FIELD-OF-VIEW)
- NATURAL ENVIRONMENT INDUCED SOURCES
  - DEBRIS/MICROMETEROIDS
  - LONG TERM THERMAL CYCLING/UV DEGRADATION
  - ATOMIC OXYGEN
- FIELD-OF-VIEW INTERFERENCE
  - VENT/THRUSTER PLUME
  - RANDOM PARTICULATES
  - SURFACE OR PLUME INDUCED "GLOW"
- GROUND TESTS LIMITATIONS
  - SIMULATING LONG TERM CHARACTERISTICS IN SHORT TERM TESTS
- FLIGHT TEST LIMITATIONS
  - FIXED PARAMETERS
  - SHORT MISSIONS
  - PRIORITIES
  - UNEXPECTED SOURCES/EVENTS

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

**2.1 Atmospheric Effects and Contamination**

***Atmospheric Effects & Contamination Technology Development Needs***

**Lyle E. Bareiss**

Martin Marietta Space Systems Company, Astronautics Group

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS\***

- LONG TERM MISSION CONTAMINATION EFFECTS
- ATOMIC OXYGEN EFFECTS MEASUREMENTS
- CONTAMINATION ABATEMENT EXPERIMENTS
  - PURGE SYSTEMS
  - INNOVATIVE COATINGS
  - VOLATILE COATINGS
- IMPROVED CONTAMINATION SENSORS
  - DEPOSITION/SURFACE EFFECTS
  - OPTICAL ENVIRONMENT MONITORS
- ENGINE PLUME CONTAMINATION EFFECTS
  - FLOWFIELDS
  - DEPOSITION EFFECTS
- MODEL VERIFICATION EXPERIMENTS
  - LONG DISTANCE TRANSPORT
  - RETURN FLUX MONITORING
- ON-ORBIT CLEANING EXPERIMENTS
  - BEAM DEVICES/LASERS/ETC
  - USE OF AMBIENT ATOMIC OXYGEN
- SURFACE GLOW/PROMPT ENHANCEMENT MONITORS
  - AFE TYPE RADIOMETERS/SPECTROMETERS
- CRYOGENIC DEPOSITION EXPERIMENTS
- RAM DENSITY ENHANCEMENT STUDIES
- ON-ORBIT CONTAMINATION EFFECTS EXPERIMENTS
  - COMBINED ENVIRONMENTS
  - CONTROLLED SOURCES
  - PARTICLE ENVIRONMENT MONITORS

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\* INTERNAL CONTAMINATION ISSUES ADDRESSED  
IN THEME AREA #4

INSTEP88 Workshop OAST Technology For the Future Part 2: Critical Technologies	INSTEP Technology Themes
Theme 2 of 8	<div> <div> <b>SPACE ENVIRONMENTAL EFFECTS</b>            2.1 Atmospheric Effects and Contamination  <i>Hyperthermal Interactions of Atmospheric Species with Spacecraft</i>              John Gregory            University of Alabama in Huntsville, College of Science         </div> <div>           Theme 1 of 8         </div> </div>
<div> <p align="center"><b><u>INTRODUCTION/BACKGROUND</u></b></p> <p>           OBJECTS IN LOW EARTH ORBIT PASS THROUGH THE AMBIENT ATMOSPHERE AT 7-8 KM/SEC. IN THE REFERENCE FRAME OF THE OBJECT THE GAS HAS AN EQUIVALENT TEMPERATURE OF 100,000°K, OR A KINETIC ENERGY (FOR O ATOMS) OF ABOUT 5eV/ATOM. THIS IS A RELATIVELY UNSTUDIED REGION OF CHEMISTRY AND PHYSICS AND ONE WHERE ENERGETIC NEW PROCESSES MIGHT BE EXPECTED. OBSERVED PROBLEM EFFECTS INCLUDE:         </p> <ul style="list-style-type: none"> <li>O SURFACE EROSION</li> <li>O SURFACE PROPERTY MODIFICATION: OPTICAL, THERMAL, ELECTRICAL</li> <li>O SURFACE AND FREE-MOLECULAR GLOW</li> <li>O MOMENTUM ACCOMMODATION UNCERTAINTY</li> </ul> </div>	
<div> <p><b>SCATTERING STUDIES</b></p> <ul style="list-style-type: none"> <li>O DYNAMICS OF SCATTERING ARE COMPLETELY DETERMINED BY THE POTENTIAL ENERGY OF INTERACTION BETWEEN ATOMS OF GAS AND SOLID.</li> <li>O EXPERIMENTAL SYSTEMS CONTAIN (1) THE BEAM, (2) THE DETECTOR, AND (3) THE TARGET SURFACE.</li> <li>O IDEAL MEASUREMENTS WOULD BE (IN ABSOLUTE NUMBERS OF ATOMS): VELOCITY DISTRIBUTION OF INCIDENT BEAM AND VELOCITY DISTRIBUTION OF REFLECTED BEAM MEASURED OVER ALL ANGLES.</li> <li>O VERY LITTLE DATA EXISTS ON 5 eV SCATTERING BECAUSE OF EXPERIMENTAL DIFFICULTY.</li> <li>O FOR REACTIVE SCATTERING, ALSO NEED ANGULAR AND VELOCITY DISTRIBUTIONS OF PRODUCT MOLECULES</li> </ul> </div>	

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

**2.1 Atmospheric Effects and Contamination**

***Hyperthermal Interactions of Atmospheric Species with Spacecraft***

**John Gregory**

University of Alabama in Huntsville, College of Science

**TECHNOLOGY NEEDS**

- O A BETTER UNDERSTANDING OF THE PHYSICS AND CHEMISTRY OF GAS SURFACE AND GAS-GAS INTERACTIONS IN THE HYPERTHERMAL REGIME IS NEEDED.**
- O AN UNDERSTANDING OF THE MECHANISM OF SURFACE CHEMICAL REACTIONS WOULD ALLOW QUANTITATIVE PREDICTION OF EFFECTS FOR NEW MATERIAL-OXYGEN DOSE COMBINATIONS WITHOUT EXHAUSTIVE TESTING AND COMPLETE SIMULATION.**
- O AN UNDERSTANDING OF THE SCATTERING PROCESS IS NEEDED TO PREDICT AND PERHAPS CONTROL ENERGY AND MOMENTUM ACCOMMODATION AND TO PREDICT SECONDARY EFFECTS OF SCATTERED ATOMS.**
- O CHEAPER METHODS OF MONITORING THE DENSITY OR FLUX OF ATMOSPHERIC SPECIES ARE NEEDED.**
- O PROBLEMS WITH SIMULATORS**
  - O PRESENCE OF IONS, METASTABLE AND EXCITED ATOMS OR MOLECULES**
  - O SIMULTANEOUS UV IRRADIATION**
  - O UNCERTAIN BACKGROUND VACUUM CONDITIONS**
  - O VELOCITY (ENERGY) PROFILE; (RATE = R(E)?)**
  - O ANGULAR DISTRIBUTION PROFILE (MORPHOLOGY)**
  - O FLUX RATE (R =  $kI$ ?)**
- O FOR EACH EXPERIMENTAL APPARATUS CONDITION AND CHEMICAL SYSTEM IT MUST BE REASONABLY WELL ESTABLISHED THAT THE ABOVE FACTORS DO NOT MATERIALLY AFFECT REACTION MECHANISMS OR MEASURED RATES.**
- O NEEDED GLOW INFORMATION (IN-SPACE)**

**INTENSITY AS A FUNCTION OF:**

- O WAVELENGTH**
- O ALTITUDE**
- O VELOCITY VECTOR**
- O SURFACE MATERIAL**
- O TIME AFTER LAUNCH**
- O SPATIAL EXTENT**

**MOST IMPORTANT IS TO IDENTIFY THE SPECTRA OF THE EMITTING SPECIES**

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 1 of 8

**2.1 Atmospheric Effects and Contamination**

***Hyperthermal Interactions of Atmospheric Species with Spacecraft***

**John Gregory**

University of Alabama in Huntsville, College of Science

**WHAT'S NEEDED TO ELUCIDATE REACTION MECHANISMS**

**MEASURE REACTION RATES AS FUNCTION OF:**

- O MATERIAL**
- O TEMPERATURE**
- O OXYGEN ATOM FLUX**
- O OXYGEN ATOM ENERGY**

**MATERIAL TYPES:**

- O ALIPHATIC AND AROMATIC POLYMERS OF DIFFERENT TYPES**
- O METALS**
- O OXIDES**
- O OTHER; EG. C, MoS<sub>2</sub>**

**MANY OF THE SURFACE REACTIONS ARE COMPLEX AND MULTI-STEPPED. A VARIETY OF INSTRUMENTAL TECHNIQUES ARE NEEDED TO MEASURE THESE RATES AND MOST OF THESE STUDIES MUST BE DONE IN THE LABORATORY.**

**IN-SPACE TECHNOLOGY NEEDS**

- O IMPROVED TECHNIQUES FOR MEASURING REACTION RATES IN SPACE**
- O PRECISE, REPRODUCIBLE RATES MEASURED IN SPACE NEEDED FOR VERIFICATION OF SIMULATORS**
- O ATOMIC OXYGEN AND MOLECULAR NITROGEN DOSIMETERS**
- O NOVEL INSTRUMENTATION TO CHARACTERIZE IR-VISIBLE-UV GLOWS AND TEST GLOW HYPOTHESES**
- O IMPROVED INSTRUMENTATION FOR SCATTERING STUDIES TO VERIFY WORK AT SIMULATORS**

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.2 Micrometeoroids and Debris**

***Detection and Measurement of the Orbital Debris Environment***

**Faith Vilas**  
NASA Johnson Space Center

**METEOROID AND DEBRIS ENVIRONMENT**

- 200 KG OF METEOROID MASS EXIST WITHIN 2000 KM OF EARTH'S SURFACE.
- 3,000,000 KG OF MAN-MADE OBJECT MASS EXIST WITHIN 2000 KM OF EARTH'S SURFACE.
- AVERAGE TOTAL INCREASE IN LEO DEBRIS HAS BEEN 5% PER YEAR.
- DEBRIS HAZARD IS LARGE ENOUGH TO AFFECT THE SPACE STATION DESIGN.
  - IMPACT DAMAGE FROM LARGE PIECES.
  - SURFACE DEGRADATION/EROSION FROM SMALL PARTICLES.

**TECHNOLOGY NEEDS: NEAR TERM**

- SPACE-BASED DEBRIS DETECTION SYSTEMS NEED TO BE DEVELOPED TO MONITOR LEO ENVIRONMENT IN DIFFERENT SPECTRAL RANGES.
- NEW MATERIALS AND CONCEPTS FOR SHIELDING SPACECRAFT MUST BE DEVELOPED.

**TECHNOLOGY NEEDS: LONGER TERM**

- SPACE-BASED COLLISION WARNING SYSTEMS NEED TO BE DEVELOPED FOR MANNED AND UNMANNED SPACECRAFT.
- DEBRIS REMOVAL SYSTEMS SHOULD BE STUDIED.
- IN-SITU METHODS OF REMOVING OR DEFLECTING A DEBRIS PIECE WHEN IMPACT IS IMMINENT MUST BE DEVELOPED.
- SPACECRAFT MATERIALS MUST BE DESIGNED WHICH WILL MINIMIZE DEGRADATION IN ORDER TO MINIMIZE FUTURE ENVIRONMENT CONTAMINATION, PRESERVE OTHER SPACE ENVIRONMENT FROM DEBRIS CONTAMINATION.

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

2.2 Micrometeoroids and Debris

*Detection and Measurement of the Orbital Debris Environment*

Faith Vilas  
NASA Johnson Space Center

**IN-SPACE EXPERIMENTS NEEDS: ENVIRONMENT DETECTION**

- EXTEND DATA ON DISTRIBUTION OF DEBRIS PARTICLE SIZE WITH ALTITUDE TO PARTICLES  $\leq 10$  CM THROUGH 2000 KM ALTITUDE.
- DETERMINE MEAN ALBEDO (% REFLECTIVITY) OR ALBEDOS OF DEBRIS.
- MONITOR TEMPORAL CHANGES IN LEO DEBRIS ENVIRONMENT.
- MONITOR LEO DEBRIS ENVIRONMENT CHANGES AFTER SPECIFIC EVENTS.

**IN-SPACE EXPERIMENT NEEDS: COLLISION WARNING DEVELOPMENT**

- OPTIMIZE DETECTOR SELECTION FROM LEO DEBRIS THERMAL HEATING INFORMATION.
- IDENTIFY NOISE OR FALSE SIGNAL SOURCES WHICH COULD AFFECT COLLISION WARNING SYSTEMS.
- TEST DETECTOR SYSTEMS IN SITU.

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

2.2 Micrometeoroids and Debris

*Design Considerations for Space Debris: An Industry Viewpoint*

Dr. H.W. Babel  
McDonnell Douglas Astronautics Company

**INTRODUCTION/BACKGROUND  
ENVIRONMENT & SHIELD CAPABILITY**

- Debris has become much more severe than micrometeoroids
- Debris flux below 10 cm based primarily on analytic projections

**INTRODUCTION AND BACKGROUND  
DEBRIS CONSIDERATIONS**

	In-Space	Ground Simulation Facilities
Velocity	1 - 14 km/sec Peak flux around 12 km/sec	To 8 km/sec for 1 cm dia spherical Al particle
Particle shape	Fragments	Spheres and rods
Alloy	Approx. 90% aluminum	Al and to a lesser extent other material
Mass	Estimates only	To 18 gm
Angle of Impact	All	Studied for spherical particles

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.2 Micrometeoroids and Debris**

***Design Considerations for Space Debris: An Industry Viewpoint***

**Dr. H.W. Babel**  
McDonnell Douglas Astronautics Company

**TECHNOLOGY NEEDS  
PREVENT LOSS OF SPACECRAFT  
OR LIFE FROM LARGE PARTICLES**

**Large size debris particles (>10 cm)**

- **Spacecraft avoidance maneuver**
  - Need high accuracy tracking system
  - Need early warning - 2 hours before impact
- **Mitigation concepts**
  - Deflect particle orbit, disintegrate, vaporize
  - Sweep out the debris

**TECHNOLOGY NEEDS  
PREVENT LOSS OF SPACECRAFT  
OR LIFE FOR 1 TO 10 CM PARTICLES**

**Medium size debris particles (~ 1 to 10 cm)**

- **Validation of flux predictions based on debris measurements**
- **Definition of debris particles - shape, alloy, and size**
- **Ability to test design concepts under realistic conditions**
  - Ground test facilities
  - In-space
- **Lighter weight shield concepts**

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.2 Micrometeoroids and Debris**

***Design Considerations for Space Debris: An Industry Viewpoint***

**Dr. H.W. Babel**  
McDonnell Douglas Astronautics Company

**EXAMPLES OF POSSIBLE IN-SPACE  
EXPERIMENTS RELATIVE TO DEBRIS**

**Debris definition concept**

- **Move active debris capture system in debris path - slow down and capture such as done for bullets**
- **Develop a large area passive capture system that can be deployed; e. g., multiple pocket capture systems (in concept like a down quilt)**

**Debris mitigation**

- **Passive large area screens that slow particles as they pass through, so they re-enter quickly. Select screen materials that do not cause secondary ejecta**

**Shield evaluation in space**

- **Seed projectile(s) and subsequently deploy tethered shield concept to be impacted. Ensure impact and retrieve shield for post test evaluation. Measure relative velocity between particle and shield. Seeded particles to re-enter quickly if experiment aborted.**

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

2.2 Micrometeoroids and Debris

***Space Debris Environment Definition***

Dr. Robert D. Culp

University of Colorado

Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research

**INTRODUCTION/BACKGROUND**

- o Natural Environment - micrometeoroids: constant
- o Artificial Space Debris: increasing
  - Sources and Sinks
  - Trackable and Untrackable
- o Hazards from Untrackable Space Debris
  - Mission Catastrophic
  - Mission Degrading
- o Necessity of Modeling and Simulating Debris

**TECHNOLOGY NEEDS**

- o Modeling
  - Current Environment
  - Future Scenarios
- o Simulation
  - Debris Generation and Evolution
  - Specific Hazard Analysis
  - Spacecraft Breakup Models
- o Debris Detection and Verification
- o Model Validation

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.2 Micrometeoroids and Debris**

***Space Debris Environment Definition***

**Dr. Robert D. Culp**

University of Colorado

Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research

**MODELING AND SIMULATION**

- o University of Colorado Debris Models
- o NASA Johnson Space Center Analytic Debris Models
- o U.S. Air Force Space Command SMART Catalog
  - Extended Catalog
  - Statistical Database for Space Debris
  - Hybrid Database
- o Feedback from Debris Sampling
  - Validation of Models
  - Updating of Databases

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- o On-Orbit Sampling
  - Quicksat
  - LDEF Retrieval and Analysis
  - Future Sampling
- o Damage-model Validation
  - Breakup Simulation
  - Reconciliation of Results with Other Space Experiments
- o Shielding Testing and Model Validation

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

2.2 Micrometeoroids and Debris

***Space Debris Environment Definition***

**Dr. Robert D. Culp**

University of Colorado

Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research

**SUMMARY/RECOMMENDATIONS**

- o Modeling/Simulation Development
- o Detection/Sampling for Validation and Updating
- o On-Orbit Hazard Verification
- o On-Orbit Shielding Verification

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Effects of Charged Particles and Electromagnetic Radiation on Structural Materials and Coatings***

**W.S. Slomp and S.S. Tompkins**  
NASA Langley Research Center

**BACKGROUND**

- HIGH DOSES OF PARTICLE RADIATION DEGRADE MECHANICAL PROPERTIES OF POLYMERIC FILMS, ADHESIVES AND RESIN-MATRIX COMPOSITES
- PRECISION SPACE STRUCTURES REQUIRE LOW CTE, STIFF MATERIALS
- ELECTRON RADIATION WITH THERMAL CYCLING DEGRADES CTE OF POLYMERIC-MATRIX COMPOSITES
- SOLAR UV RADIATION AFFECTS OPTICAL AND MECHANICAL PROPERTIES OF MOST POLYMERIC FILMS AND COATINGS
- DATA NOT AVAILABLE ON LONG-TERM EFFECTS OF RADIATION AND THERMAL CYCLING ON STRUCTURAL MATERIALS AND COATINGS IN SPACE

**TECHNOLOGY PROGRAMS**

- PRECISION SEGMENTED REFLECTOR (LARGE DEPLOYABLE REFLECTOR)
- SPACE STATION FREEDOM
- SPACE DEFENSE INITIATIVE
- GLOBAL CLIMATE CHANGE PROGRAM
- NASA BASE TECHNOLOGY RESEARCH ON SPACE ENVIRONMENTAL EFFECTS

**CURRENT FLIGHT EXPERIMENTS**

- LDEF (RETURN LATE 1989)
- EOIM-3
- DELTA STAR

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Effects of Charged Particles and Electromagnetic Radiation on Structural Materials and Coatings***

**W.S. Slomp and S.S. Tompkins**  
NASA Langley Research Center

**TECHNOLOGY NEEDS**

- ABILITY TO PREDICT USEFUL LIFETIMES OF FILMS, COATINGS, ADHESIVES, AND STRUCTURAL MATERIALS IN ANY SPACE SERVICE ENVIRONMENT
- LONG-TERM SYNERGISTIC EFFECTS DATA BASE (UV, e<sup>-</sup>, P<sup>+</sup>, TEMP. CYCLING)
- ACCELERATED TESTING METHODOLOGY FOR SIMULATION OF REAL-TIME SPACE RADIATION EFFECTS
- STANDARDIZED UV SOURCES AND TEST TECHNIQUES
- MODEL COMPOUNDS TO ELUCIDATE RADIATION EFFECTS FOR DEGRADATION MECHANISM STUDIES
- MATERIALS DESIGNED TO UNDERSTAND EXPOSURE ENVIRONMENT
- MECHANICAL PROPERTY TESTING IN-SPACE WITH RADIATION EXPOSURE

**IN-SPACE NEEDS**

- RADIATION EFFECTS FLIGHT DATA FOR VERIFICATION OF LABORATORY TESTING AND DEVELOPMENT OF ANALYTICAL MODELS
- RADIATION EFFECTS DATA IN SERVICE ENVIRONMENTS OF GEO, INNER VAN ALLEN BELT, LEO EQUATORIAL AND POLAR
- SPACE RADIATION ENVIRONMENT DATA FOR PROTONS < 10 meV AND ELECTRONS < 1 meV
- MECHANICAL/OPTICAL PROPERTY DATA IN SPACE
- "SMART" MATERIALS WHICH MONITOR IN-SPACE PERFORMANCE
- ADDITIONAL LONG-TERM FLIGHT OPPORTUNITIES

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Effects of Charged Particles and Electromagnetic Radiation on Structural Materials and Coatings***

**W.S. Siemp and S.S. Tompkins**  
NASA Langley Research Center

**SUMMARY**

- **PRECISION SPACE STRUCTURES ARE REQUIRED FOR SPACE ANTENNA SYSTEMS AND MOST LARGE SPACE STRUCTURAL APPLICATIONS**
- **LONG-TERM IN-SPACE DATA NEEDED TO ESTABLISH RADIATION DURABILITY**
- **LONG-TERM FLIGHTS ALSO NEEDED IN EACH PROPOSED FLIGHT ENVIRONMENT TO PROVIDE:**
  - **DATA TO IMPROVE ENVIRONMENT MODELS**
  - **DATA FOR LABORATORY CORRELATION**
  - **VERIFICATION OF LONG-TERM PERFORMANCE PREDICTIONS FROM SHORT-TERM FLIGHT AND LAB DATA**

Theme 2 of 8

## **SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

### **2.3 Charged Particles and Electromagnetic Radiation Effects *Effects on Space Systems: Technology Requirements for the Future***

H. Garrett  
Jet Propulsion Laboratory

## **INTRODUCTION/BACKGROUND**

### **WHAT WE ARE INTERESTED IN:**

- **DEFINING LONG TERM RADIATION EFFECTS ON ELECTRONIC SYSTEMS AND SENSORS.**
- **PLANNING LONG TERM MISSIONS IN HOSTILE RADIATION ENVIRONMENTS.**
- **PROTECTING AGAINST SINGLE EVENT UPSETS AND DOSAGE EFFECTS.**

## **TECHNOLOGY NEEDS**

### **NEEDS DUE TO NEW TECHNOLOGIES:**

- **REQUIRE METHODS FOR REDUCING SENSITIVITY TO HIGH-Z/HIGH ENERGY COSMIC RAY AND SOLAR FLARE PARTICLES (I.E., "VOTING", SPECIAL DESIGNS, NEW SHIELDING TECHNOLOGY).**
- **SENSITIVITY TO LATCHUP, DISPLACEMENT, AND HIGH ENERGY PROTONS MAY BECOME CONCERNS IN FUTURE GENERATIONS OF DEVICES.**
- **FIBER OPTICS AND OTHER TECHNOLOGIES THAT ARE "HARD" TO SEU'S AND OTHER RADIATION EFFECTS NEED TO BE DEVELOPED FOR SPACE USE.**
- **NEED TO DEVELOP COMPREHENSIVE TESTING METHODS FOR COMPONENTS (PARTICULARLY FOR SEU EFFECTS AND LONG TERM DOSAGE) THAT CAN SIMULATE IN-SPACE COMPOSITION AND ENERGY SPECTRA.**
- **REQUIRE COMPUTER MODELLING TOOLS FOR PREDICTING RADIATION EFFECTS ON NEW COMPONENTS.**

### **NEEDS DUE TO EXTENDED MISSIONS:**

- **NEED NEW TESTING TECHNOLOGIES CAPABLE OF SIMULATING DOSE/RATE, TOTAL DOSE, AND ANNEALING.**
- **INTERNAL CHARGING OF COMPONENTS OVER LONG TIME PERIODS NEEDS TO BE DEFINED AND ARCING CHARACTERISTICS DEFINED.**
- **LONG TERM EFFECTS OF INDUCED RADIATION/HEATING ON COMPONENTS NEED TO BE DEFINED**
- **UNIFORM TECHNIQUES FOR DEFINING/APPLYING RADIATION DESIGN MARGINS NEED TO BE DEVELOPED.**
- **NEW TECHNIQUES FOR HARDENING PARTS NEED TO BE DEVELOPED WITH PART EXPOSURES IN EXCESS OF  $10^5$  -  $10^6$  RADS TYPICAL**
- **REQUIRE INEXPENSIVE, RELIABLE RADIATION MONITORS CAPABLE OF BEING STANDARD "HOUSEKEEPING" ITEM ON ALL MISSIONS.**

Theme 2 of 8

## SPACE ENVIRONMENTAL EFFECTS

Theme 2 of 8

### 2.3 Charged Particles and Electromagnetic Radiation Effects

#### *Effects on Space Systems: Technology Requirements for the Future*

H. Garrett  
Jet Propulsion Laboratory

#### TECHNOLOGY NEEDS (CONT.)

##### NEEDS DUE TO SIZE/PROLIFERATION:

- REQUIRE CHEAP/INTRINSICALLY "HARD" COMPONENTS FOR PROLIFERATION MISSIONS (I.E., PHASED ARRAY RADAR)
- BETTER SHIELDING TECHNIQUES TO REDUCE MASS REQUIREMENTS.
- ACCURATE, USER-FRIENDLY SHIELDING MODELS CAPABLE OF MODELING COMPLEX GEOMETRIES ARE REQUIRED.
- ENVIRONMENTAL IMPACT--LARGE SIZES MAY MODIFY RADIATION AND PARTICULATE ENVIRONMENTS.
- BETTER MODELS OF ENVIRONMENT FOR MISSION PLANNING AND OPERATIONS ARE REQUIRED (SOLAR FLARES, GEOMAGNETIC STORMS, ETC.)

##### NEEDS DUE TO NEW ENVIRONMENTS:

- DEVICES REQUIRED TO SURVIVE NEAR NUCLEAR REACTORS (SP-100) WILL NEED TO WITHSTAND DOSAGES IN EXCESS OF  $10^6$  -  $10^7$  RADS
- INCREASING UTILIZATION OF THE 1000-30000 KM ALTITUDE RANGE WILL REQUIRE MUCH MORE RADIATION-INSENSITIVE DEVICES. BOTH DOSE/RATE AND DOSAGE EFFECTS WILL BE OF CONCERN.
- LONG TERM MISSIONS IN INTERPLANETARY AND INTERSTELLAR SPACE WILL REQUIRE SELF-ANNEALING PARTS.
- DOD-UNIQUE REQUIREMENTS FOR SURVIVABILITY (I.E., MICROWAVE ENVIRONMENTS, NUCLEAR WEAPONS) NEED TO BE INCLUDED.
- NEW, UNEXPECTED EFFECTS ARE LIKELY! TECHNIQUES FOR IDENTIFYING AND FOR RAPIDLY COPING WITH THESE ARE REQUIRED.

#### SUMMARY/RECOMMENDATIONS

##### SPACE RADIATION EFFECTS:

- RADIATION EFFECTS ON SYSTEMS WILL BE A CONTINUING AND POTENTIALLY GROWING CONCERN IN THE DECADES AHEAD. NEW, MORE STRINGENT MISSION RADIATION REQUIREMENTS ARE INEVITABLE.
- A CONSISTENT, LONG RANGE POLICY OF MONITORING THE ENVIRONMENT AND EVALUATING NEW TECHNOLOGIES IS CRUCIAL TO CONTROLLING THE IMPACT OF RADIATION.
- INCREASES IN HARDENING AND REDUCTIONS IN SHIELDING MASS REQUIREMENTS ARE THE KEYS TO SUBSTANTIAL MISSION ENHANCEMENT.
- GROUND TEST, MODELLING (ENVIRONMENT AND INTERACTION), DEVELOPMENT OF DESIGN GUIDELINES, AND IN SITU EXPERIMENTATION MUST GO HAND-IN-HAND.

##### KEY EXPERIMENTS:

- COMPREHENSIVE ELECTRONIC COMPONENT TESTING FACILITY
- FLARE/STORM PREDICTION CAPABILITY
- STANDARDIZED ENVIRONMENTAL MONITORING PACKAGES
- IN-SPACE RADIATION TESTING FACILITY

Theme 2 of 8

## SPACE ENVIRONMENTAL EFFECTS

Theme 2 of 8

### 2.3 Charged Particles and Electromagnetic Radiation Effects

#### *Electromagnetic and Plasma Environment Interactions: Technology Needs For the Future*

G. Murphy  
Jet Propulsion Laboratory

## INTRODUCTION/BACKGROUND

- MISSIONS OF THE FUTURE REQUIRE TECHNOLOGICAL ADVANCES IN ELECTROMAGNETICS AND SPACE ENVIRONMENT INTERACTIONS.
- THE DRIVERS FOR THESE NEW TECHNOLOGIES ARE THREE FOLD:
  1. INCREASED DURATION AND RELIABILITY REQUIREMENTS;
  2. INCREASED COMPLEXITY OF PAYLOADS AND SUBSYSTEMS;
  3. INCREASED SUSCEPTIBILITY OF COMPLEX SENSORS AND SUBSYSTEMS.
- THESE FACTORS ARE COMPLICATED BY THE NEED FOR INCREASED POWER LEVELS, PROVISION FOR ON-ORBIT INTEGRATION/RECONFIGURATION, AND USE OF ROBOTIC SERVICERS.

## MISSION APPLICATIONS

- SPACE STATION ATTACHED PAYLOAD AND RACKS MUST BE INTEGRATED ON ORBIT.
- SYSTEMS WILL BE FLOWN THAT ARE TOO LARGE TO TEST BY MIL-STD 461 METHODS AND WILL NOT FIT IN SCREEN ROOMS OR TEST CHAMBERS.
- LARGE STRUCTURES SUCH AS ACTIVE ELEMENT PHASED ARRAYS REQUIRE SPECIAL CONSIDERATION FOR ESD AND EM COMPATIBILITY.
- MATERIALS THAT SERVE TO PROTECT A SYSTEM CHANGE WITH AGE (UV, RADIATION, SURFACE CONTAMINATION, OXYGEN EROSION, DEBRIS IMPACT)
- NEW GENERATION SENSORS AND INSTRUMENTS NEED HIGH DENSITY ELECTRONICS, HIGH CLOCK FREQUENCIES, AND LOW BACKGROUND NOISE.
- HIGH POWER SYSTEMS AND THEIR DISTRIBUTION ARCHITECTURES MUST CONSIDER EMI AND PLASMA EFFECTS FROM INCEPTION.

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Electromagnetic and Plasma Environment Interactions: Technology Needs For the Future***

**G. Murphy**  
Jet Propulsion Laboratory

**TECHNOLOGY NEEDS**

- **THE NEEDS WILL BE FOCUSED ON THREE AREAS: EMI/EMC TECHNOLOGY; PLASMA/NEUTRAL INTERACTIONS; SENSOR DEVELOPMENT.**
- **THE EMI/EMC TECHNOLOGY NEEDS ARE DRIVEN BY SYSTEM AND OPERATIONAL REQUIREMENTS**
  1. **EM ENVIRONMENT MUST INCLUDE INTERACTION WITH THE PLASMA**
  2. **ESD DESIGN MUST BE COMPATIBLE WITH THERMAL REQUIREMENTS AND WEIGHT LIMITATIONS.**
  3. **SOFTWARE VERIFIED AS NON-SUSCEPTIBLE TO EMI**
  4. **METHODS OF DIAGNOSING AND SOLVING EMC PROBLEMS ON ORBIT**
- **PLASMA INTERACTIONS DESCRIBE INTERRELATIONSHIP BETWEEN THE PLASMA ENVIRONMENT (LEO, GEO, INTERPLANETARY) AND THE SYSTEM**
- **ISSUES THAT NEED RESOLUTION IN ORDER TO ACCURATELY PREDICT THE CONSEQUENCES OF CERTAIN ENVIRONMENT/SYSTEM COMBINATIONS.**
  1. **PLASMA CHEMISTRY WITH CONTAMINANT EFFLUENTS**
  2. **CHARACTERIZATION OF MATERIALS (PHOTO EMISSION, SECONDARY PRODUCTION, ION SPUTTERING ETC.)**
  3. **CONTROL OF CHARGE BUILDUP ON LARGE SURFACES**
  4. **MODEL OF COMBINED NEUTRAL/PLASMA ENVIRONMENTS NEAR LARGE OBJECTS**
  5. **BREAKDOWN THRESHOLDS, DISCHARGE CURRENTS AS FUNCTION OF GEOMETRY, MATERIAL, AND PLASMA DENSITY.**
- **TO BETTER UNDERSTAND AND MODEL THE ENVIRONMENT EFFECTS AND EMI, NEW SENSOR TECHNOLOGY MUST BE DEVELOPED.**
  1. **SFR'S AND OTHER FLIGHT QUALIFIED, LIGHT WEIGHT DIAGNOSTIC EQUIPMENT**
  2. **ION/NEUTRAL MASS SPECTRAL ANALYSIS WITH TRACE ELEMENT SENSITIVITY**
  3. **DISTRIBUTED SENSORS AS STANDARD COMPONENTS OF LARGE SYSTEMS**
  4. **MEASUREMENT OF DISTRIBUTION FUNCTION OF PARTICULATE MATERIALS**

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Electromagnetic and Plasma Environment Interactions: Technology Needs For the Future***

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Jet Propulsion Laboratory

**EXPERIMENTATION NEEDS**

- **GROUND BASED EXPERIMENTS/STANDARDS/MODELS**
- **EMI/EMC:**
  1. **TOOLS FOR SIMULATING ON-BOARD PERFORMANCE BASED ON GROUND TESTS.**
  2. **LONG-LIFE MATERIALS WITH GOOD CONDUCTIVITY/THERMAL PROPERTIES**
  3. **TOOLS FOR VERIFYING SOFTWARE RELIABILITY IN EM ENVIRONMENT**
- **PLASMA INTERACTIONS**
  1. **CROSS SECTIONS FOR CHEMICAL REACTIONS BETWEEN AMBIENT AND CONTAMINANTS**
  2. **PREDICT ARC THRESHOLD WITH ACTIVE AND PASSIVE DEVICES AS FUNCTION OF GEOMETRY, MATERIAL, AND PLASMA DENSITY**
- **SENSORS**
  1. **CONVERT LABORATORY SENSORS TO SPACE ENVIRONMENT**
  2. **DEVELOP TECHNIQUES FOR MORE SENSITIVE SPECTROMETRY**

**EXPERIMENT NEEDS--FLIGHT**

- **EMI/EMC:**
  1. **FLIGHT TEST NEW CONDUCTIVITY COATINGS (LONGEVITY)**
  2. **VERIFY GROUND MEASUREMENTS OF ARCS**
- **PLASMA/INTERACTIONS**
  1. **MEASURE DYNAMICS OF PLASMA AND NEUTRAL GAS CLOUDS TO VERIFY AND IMPROVE MODELS**
  2. **CHARGING OF LARGE STRUCTURES IN WAKE AND IN POLAR ORBIT**
- **SENSORS**
  1. **INVESTIGATE USE OF SUPERCONDUCTING TECHNOLOGY IN SENSORS**
  2. **DEVELOPMENT OF SMALL, AUTONOMOUS DISTRIBUTED SENSORS.**

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Space Environmental Effects Critical Technology Requirements***

Lubert J. Leger  
NASA Johnson Space Center

**NASA/SDI MEETING ON SPACE ENVIRONMENTAL EFFECTS**

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- MEETING HELD DURING MID 1988 TO REVIEW TECHNOLOGY NEEDS FOR SPACE ENVIRONMENTAL EFFECTS
- RESULTS OF MEETING EMPHASIZED THE FOLLOWING:
  - SUBJECT FOR ONGOING EXPERIMENTS
    - LDEF
    - EOIM III
    - OTHER MISSIONS SUCH AS DELTA STAR
  - NEED FOR SIMULATION FACILITIES
  - NEED FOR FUTURE EXPERIMENT CARRIERS FOR EXTENSIVE STUDY OF EFFECTS
- IN-STEP MEETING WAS THEREFORE FOCUSED MORE DIRECTLY TO IN-SPACE EXPERIMENT NEEDS THAT WOULD BE THE SUBJECT OF THE NEXT OUT-REACH SOLICITATION

**MISSION RELATIONSHIP**

- FUTURE NATIONAL SPACE MISSIONS ARE MORE COMPLEX, REQUIRE LONG LIFE AND UTILIZE MORE SENSITIVE INSTRUMENTATION
- INFORMATION GAINED OVER THE LAST DECADE HAS IDENTIFIED ASPECTS OF THE ENVIRONMENT WHICH COULD BE LIFE LIMITING TO LARGE SPACECRAFT
- DEBRIS - IMPACT BY 30 CM SIZE OBJECT IN 30 YEARS
- ATOMIC OXYGEN - COMPLETE REMOVAL BY EROSION OF SPACE STATION UNCOATED STRUCTURAL TUBES IN 15 YEARS
- SUCCESSFUL ACCOMPLISHMENT OF FUTURE MISSIONS REQUIRES INCREASED EMPHASIS ON ENVIRONMENTAL EFFECTS
- LONG LIFE ENHANCES ENVIRONMENTAL EFFECTS
- NEW UNDERSTANDING OF ENVIRONMENT AND EFFECTS ON SPACECRAFT

Theme 2 of 8

## SPACE ENVIRONMENTAL EFFECTS

Theme 2 of 8

### 2.3 Charged Particles and Electromagnetic Radiation Effects

#### *Space Environmental Effects Critical Technology Requirements*

Lubert J. Leger  
NASA Johnson Space Center

## WHY IN-SPACE EXPERIMENTS?

- o WELL CHARACTERIZED ENVIRONMENT NECESSARY TO SUPPORT PROPER DESIGN OF FUTURE MISSIONS - THEME ENCOURAGES BROAD BASE MEASUREMENTS
- o ENVIRONMENT SIMULATION DIFFICULT
  - o NOT POSSIBLE TO SIMULATE MANY ASPECTS OF THE ENVIRONMENT - ENERGY, COMPOSITION
  - o INTERACTION OF THE ENVIRONMENT WITH SURFACES IS SENSITIVE TO MANY PARAMETERS WHICH ARE HARD TO CONTROL
  - o NEED IN-SPACE DATA TO VERIFY GROUND BASED SIMULATION SYSTEMS

## ATMOSPHERIC EFFECTS AND CONTAMINATION SUMMARY

To develop materials and material configurations which are environmentally durable and functionally compatible with long duration space missions, it is necessary to perform in-space experiments to quantify and characterize interactions with the atmospheric and space system environment. This data will provide for an understanding of mechanisms involved and enable the development of ground based modeling and simulation technologies needed for materials and material applications development.

Critical technology needs identified include: active measurement of atomic oxygen flux for accurate real time data on all atmospheric interaction phenomena; glow phenomena information for compatible sensor design; contamination effects and atomic oxygen erosion data (direct and scattered reactions) for durability and functional performance prediction; contamination effects data and abatement techniques for long term space system durability and spacecraft/atmosphere interaction.

Theme 2 of 8

## SPACE ENVIRONMENTAL EFFECTS

Theme 2 of 8

### 2.3 Charged Particles and Electromagnetic Radiation Effects *Space Environmental Effects Critical Technology Requirements*

Lubert J. Leger  
NASA Johnson Space Center

#### ATMOSPHERIC EFFECTS AND CONTAMINATION SUMMARY

<u>PRIORITY</u>	<u>AVERAGE SCORE</u>	<u>IN-SPACE TECHNOLOGY NEED</u>
1	1.3	Active Measurement of A/O flux
2	1.7	Glow - LEO
2	1.7	Data to enable ground based modeling and simulation
3	1.9	Materials Erosion
4	2.0	Contamination - All Altitudes
4	2.0	Demonstration of Contamination abatement/reduction techniques
5	2.1	Drag - Low Earth Orbit
5	2.1	Measurements of Contamination generation/transport/effects (all phases) for improved model.
6	2.7	Contamination Design guidelines Experiments
6	2.7	Measurements of perturbations to the ambient environment due to spacecraft/ atmospheric interactions.

#### MICROMETEORIDS AND DEBRIS SUMMARY

- CHARACTERIZATION OF THE LEO DEBRIS ENVIRONMENT AND ITS EFFECT ON SPACECRAFT
  - LEO ENVIRONMENT PARTICLE SIZE DISTRIBUTION, SPECTRAL PROPERTIES CHARACTERIZATION
  - LONG TERM SURFACED DEGRADATION FROM DEBRIS
  - IN-SPACE SAMPLING OF COLLISION FRAGMENTS: SIZE, SHAPE AND COMPOSITION
- IN-SPACE TESTING OF PROTECTION AND MITIGATION TECHNIQUES FROM LEO DEBRIS
  - DEVELOPMENT AND VERIFICATION OF COLLISION WARNING SYSTEMS TECHNOLOGY IN-SITU
  - EVALUATION OF SHIELD CONCEPTS IN-SITU
  - EVALUATION AND VERIFICATION OF MITIGATION TECHNIQUES IN-SITU

Theme 2 of 8

## SPACE ENVIRONMENTAL EFFECTS

Theme 2 of 8

### 2.3 Charged Particles and Electromagnetic Radiation Effects

#### *Space Environmental Effects Critical Technology Requirements*

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NASA Johnson Space Center

#### MICROMETEORIDS AND DEBRIS SUMMARY

<u>PRIORITY</u>	<u>AVERAGE SCORE</u>	<u>IN-SPACE TECHNOLOGY NEED</u>
1	1.14	LEO PARTICLE DISTRIBUTION
2	2.27	COLLISION WARNING SYSTEM
3	2.29	IN-SPACE DEBRIS SAMPLING
4	2.44	IN-SITU SHIELD EVALUATION
5	2.80	SURFACE DEGRADATION
6	3.00	MITIGATION TECHNIQUES
7	3.29	EXTERNAL TANK USE

#### CHARGED PARTICLES AND ELECTROMAGNETIC RADIATION EFFECTS SUMMARY

- MONITORING OF RADIATION ENVIRONMENT EFFECTS ON MATERIALS AND ICs
  - NEED LONG TERM, CONTINUOUS MEASUREMENTS OF MECHANICAL, OPTICAL, AND ELECTRICAL PROPERTIES IN CRITICAL ORBITS (LEO, GEO, POLAR)
  - NEED DATA TO VALIDATE GROUND TESTING TECHNIQUES
  - NEED DATA TO UPGRADE/VALIDATE RADIATION AND SOLAR FLARE MODELS
- NEED TO DETERMINE EFFECTS OF CHEMICAL VENTING IN LEO ON ELECTROMAGNETIC INTERFERENCE AND SURFACE DEPOSITION
- DEVELOP AND TEST IN SPACE SIMPLE, SMALL AUTONOMOUS SENSORS FOR SURFACE CHARGING, RADIATION EXPOSURE AND ELECTRIC FIELDS

Theme 2 of 8

**SPACE ENVIRONMENTAL EFFECTS**

Theme 2 of 8

**2.3 Charged Particles and Electromagnetic Radiation Effects**

***Space Environmental Effects Critical Technology Requirements***

Lubert J. Leger  
NASA Johnson Space Center

**CHARGED PARTICLES AND ELECTROMAGNETIC  
RADIATION EFFECTS SUMMARY**

<b><u>PRIORITY</u></b>	<b><u>AVERAGE SCORE</u></b>	<b><u>IN-SPACE TECHNOLOGY NEED</u></b>
1	1.7	MONITOR IN-SITU ENVIRONMENT ON CONTINUING BASIS.
2	1.8	VALIDATE GROUND TEST TECHNIQUES USING IN-SPACE EXPERIMENTS.
3	1.87	LONG-TERM IN-SPACE DATA IN PROPOSED ORBITAL ENVIRONMENTS.
4	1.91	MECHANICAL / OPTICAL PROPERTIES MEASURED IN SPACE IN A VARIETY OF ORBITS.
5	2.0	DETERMINE ELECTROMAGNETIC AND DEPOSITION CONSEQUENCES FROM THE VENTING OF EXPECTED CHEMICALS IN THE LOW EARTH ORBIT ENVIRONMENT.
5	2.0	DATA TO UPGRADE / VALIDATE RADIATION & SOLAR FLARE MODELS.
6	2.22	DEVELOP AND TEST SIMPLE, SMALL AUTONOMOUS SENSORS FOR SURFACE CHARGING, RADIATION EXPOSURE AND ELECTRIC FIELD.
7	2.44	UNDERSTAND THE MATERIAL / PLASMA INTERFACE BY TESTING LONG-TERM CONDUCTIVITY OF DIELECTRICS AND EFFECTIVENESS OF CONDUCTIVE COATINGS.
7	2.44	DETERMINE ARC ONSET VOLTAGES OF EXPECTED DIELECTRIC / METAL GEOMETRIES AND TEST DISCHARGE EMI IN LOW EARTH ORBIT CONDITIONS
8	2.45	"SMART" MATERIALS WHICH HELP CORRELATE FLIGHT DATA TO LABORATORY DATA.
9	2.6	VALIDATE SEU MODELS WITH IN-SPACE TESTS
9	2.6	DEVELOP PERMANENT IN-SPACE RADIATION TESTING FACILITY. SHOULD BE IN WORST PART OF RADIATION BELTS.
10	2.9	QUANTIFY INTERNAL CHARGING EFFECTS ON COMPONENTS.
11	3.1	TEST FIBER OPTICS SYSTEMS BEHAVIOR UNDER LONG-TERM EXPOSURE

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**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

Background and Objectives

*Review of Previous Workshops (Williamsburg 10/85, Ocean City 6/88)*

Roy McIntosh  
NASA Goddard Space Flight Center

**SUMMARY OF THE NASA/OAST SPONSORED**

**IN-SPACE RESEARCH, TECHNOLOGY  
AND  
ENGINEERING (RT&E) WORKSHOP**

HELD AT:  
WILLIAMSBURG, VA      8-10 OCTOBER, 1985

**-WORKSHOP BACKGROUND-**

- ADVENT OF THE SPACE STATION MARKS A NEW ERA OF PERMANENTLY MANNED PRESENCE IN SPACE
- EXISTING TECHNOLOGY BASE NEEDED EXPANSION IN SEVERAL KEY AREAS
- INDUSTRY AND UNIVERSITY INVOLVEMENT IN SPACE ACTIVITIES ANTICIPATED TO INCREASE
- PERCEIVED NEED TO BRING TOGETHER INDUSTRY, UNIVERSITY, AND GOVERNMENT RESEARCHERS IN A COMMON FORUM

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

Background and Objectives

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NASA Goddard Space Flight Center

### -WORKSHOP GOALS-

- IDENTIFY FUTURE NEEDS FOR IN-SPACE EXPERIMENTS IN SUPPORT OF SPACE TECHNOLOGY DEVELOPMENT, ESPECIALLY AS RELATED TO THE SPACE STATION
- VALIDATE NASA'S IN-SPACE EXPERIMENT THEME AREAS
- INITIATE A LONG-TERM PROGRAM OF OUTREACH TO UNIVERSITIES AND PRIVATE INDUSTRY TO ESTABLISH A USER COMMUNITY NETWORK
- FORM THE BASIS FOR ESTABLISHMENT OF ON-GOING TECHNICAL WORKING GROUPS

### -WORKSHOP THEME AREAS-

- SPACE STRUCTURES (DYNAMICS & CONTROL)
- FLUID MANAGEMENT
- SPACE ENVIRONMENTAL EFFECTS
- ENERGY SYSTEMS & THERMAL MANAGEMENT
- INFORMATION SYSTEMS
- AUTOMATION & ROBOTICS
- IN-SPACE OPERATIONS

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

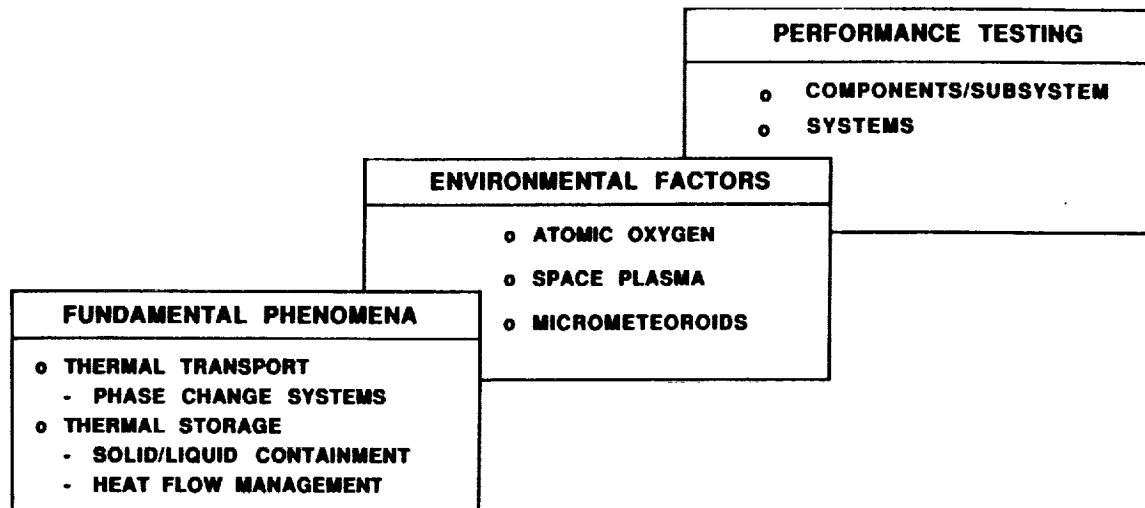
Background and Objectives

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Roy McIntosh  
NASA Goddard Space Flight Center

## ENERGY SYSTEMS AND THERMAL MANAGEMENT

### KEY TECHNOLOGY ISSUES



### -WORKSHOP RESULTS- KEY TECHNOLOGY ISSUES

- FUNDAMENTAL PHENOMENA
  - HEAT TRANSFER IN MICRO-GRAVITY
  - PHASE CHANGE/THERMAL STORAGE
- ENVIRONMENTAL CONCERNS
  - MICROMETERIDS, ATOMIC OXYGEN, SPACE PLASMA
- PERFORMANCE TESTING (IN-SPACE)
  - TWO-PHASE COMPONENTS AND SUBSYSTEMS
  - TWO-PHASE SYSTEMS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

Background and Objectives

*Review of Previous Workshops (Williamsburg 10/85, Ocean City 6/88)*

**Roy McIntosh**  
NASA Goddard Space Flight Center

**ENERGY SYSTEMS AND THERMAL MANAGEMENT**  
**GENERAL OBSERVATIONS**

- o MUCH OF PROPOSED EXPERIMENTAL EFFORT COULD BE CONDUCTED ON THE GROUND
- o MANY PROPOSED EXPERIMENTS WERE APPROPRIATE FOR PRECURSOR SHUTTLE FLIGHT
- o SOME EXPERIMENTS WERE NOT SUITED FOR SHUTTLE OR SPACE STATION
- o MOST EXPERIMENTS WERE AT THE "IDEA" LEVEL -- MINIMAL TECHNICAL DETAIL
- o TWO FUNDAMENTAL RESEARCH AREAS WERE IDENTIFIED AS REQUIRING SPACE FLIGHT
  - PHASE CHANGE/HEAT TRANSFER PHENOMENA IN ZERO-G
  - ENVIRONMENTAL EFFECTS
- o ADVANCED POWER AND THERMAL SYSTEMS WILL REQUIRE IN-SPACE EXPERIMENTAL SUPPORT

**-WORKSHOP RESULTS-  
FUTURE ACTIVITIES**

- 1986: ANNOUNCEMENT OF OPPORTUNITY FOR IN-SPACE EXPERIMENTS
  - 231 PROPOSALS RECEIVED
  - 41 PROPOSALS SELECTED, MOSTLY FOR DEFINITION PHASE EFFORT
- 1988: NASA/OAST WORKSHOP ON TWO-PHASE FLUID BEHAVIOR IN A SPACE ENVIRONMENT
- 1988: IN-STEP 88 WORKSHOP

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

Background and Objectives

*Review of Previous Workshops (Williamsburg 10/85, Ocean City 6/88)*

Roy McIntosh  
NASA Goddard Space Flight Center

SUMMARY OF THE NASA/OAST SPONSORED

WORKSHOP ON TWO-PHASE FLUID BEHAVIOR  
IN A  
SPACE ENVIRONMENT

HELD AT:

OCEAN CITY, MARYLAND 13-14 JUNE, 1988

-GENESIS OF WORKSHOP-

- NASA HQ RECEIVED A LARGE NUMBER OF PROPOSALS WHICH FOCUSED ON RESEARCH INTO TWO-PHASE FLOW PHENOMENA IN A MICROGRAVITY ENVIRONMENT. THIS SPOTLIGHTED THE PROBLEM.
- COST AND MANIFESTING CONSTRAINTS PROHIBIT MORE THAN A FEW SELECT FLIGHT EXPERIMENTS.
- CONCEPT OF A COORDINATED FLIGHT TEST PROGRAM DEVELOPED.
- HEADQUARTERS REQUESTED GSFC TO ORGANIZE AND CONDUCT A WORKSHOP TO BEGIN PLANNING FOR THIS TEST PROGRAM.

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## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

Background and Objectives

*Review of Previous Workshops (Williamsburg 10/85, Ocean City 6/88)*

**Roy McIntosh**  
NASA Goddard Space Flight Center

### -WORKSHOP GOALS-

- IDENTIFY AND CATEGORIZE/PRIORITIZE THE TECHNICAL ISSUES, CONCERNS, AND PROBLEMS INVOLVED IN DESIGNING TWO-PHASE THERMO-FLUID DYNAMIC SYSTEMS FOR SPACE APPLICATIONS.
- CONCEPTUALIZE POSSIBLE TECHNOLOGIES AND FLIGHT EXPERIMENTS TO ADDRESS THE ISSUES IDENTIFIED.

THE ABOVE WILL PROVIDE THE PRIMARY INPUTS TOWARDS DEFINITION OF THE TEST PROGRAM. WORKSHOP ITSELF DOES NOT SEEK TO DEFINE TEST PROGRAM.

### -WORKSHOP RESULTS- MAJOR TECHNICAL ISSUES

#### HARDWARE NEEDS:

- HEAT PUMPS
- LOW WEIGHT RADIATORS
- ADVANCED HEAT PIPES
  - CRYOGENIC
  - UPPER MID-TEMPERATURE (e.g. WATER)
  - HIGH TEMPERATURE
- IMPROVED MATERIALS
- STABILITY ENHANCEMENT DEVICES
- HIGH FLUX EVAPORATORS
- VAPOR SEPARATORS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

Background and Objectives

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**-WORKSHOP RESULTS-  
MAJOR TECHNICAL ISSUES**

HARDWARE NEEDS;

- HEAT PUMPS
- LOW WEIGHT RADIATORS
- ADVANCED HEAT PIPES
  - CRYOGENIC
  - UPPER MID-TEMPERATURE (e.g. WATER)
  - HIGH TEMPERATURE
- IMPROVED MATERIALS
- STABILITY ENHANCEMENT DEVICES
- HIGH FLUX EVAPORATORS
- VAPOR SEPARATORS

**-WORKSHOP RESULTS-  
MAJOR TECHNICAL ISSUES**

BASIC RESEARCH NEEDS;

- TWO-PHASE INSTABILITIES
- PROPERTIES OF MATERIALS
- ANALYTICAL MODELS
- EMPIRICAL MODELS FOR DESIGN PURPOSES

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

Background and Objectives

*Review of Previous Workshops (Williamsburg 10/85, Ocean City 6/88)*

**Roy McIntosh**  
NASA Goddard Space Flight Center

## IN STEP 88 WORKSHOP OBJECTIVES

- REVIEW STATE OF TECHNOLOGY READINESS IN  
CONVENTIONAL POWER SYSTEMS  
NUCLEAR AND DYNAMIC POWER SYSTEMS  
THERMAL MANAGEMEN
- IDENTIFY CRITICAL TECHNOLOGY NEEDS  
FOR IN SPACE EXPERIMENTS  
GOVERNMENT  
INDUSTRY  
UNIVERSITY  
AUDIENCE
- PRIORITIZE NEEDS

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.1 Dynamic and Nuclear Power Systems

#### *Dynamic and Nuclear Systems*

Dr. John M. Smith  
NASA Lewis Research Center

## MISSION APPLICATIONS

- EARTH OBSERVING MISSIONS
- MATERIALS PROCESSING PLATFORMS
- SPACE BASED AIR/OCEAN TRAFFIC CONTROL RADAR
- PRODUCTION, MANAGEMENT, STORAGE OF CRYO FLUIDS
- GEO COMMUNICATIONS PLATFORM
- MARS AND/OR PHOBOS SAMPLE ACQUISITION, ANALYSIS, RETURN
- PLANETARY ROVERS (PILOTED AND ROBOTIC)
- LUNAR AND ASTEROID RESOURCE UTILIZATION
- SPACE TRANSFER VEHICLE (NEP AND SEP)
- LUNAR OUTPOSTS TO EARLY MARS OUTPOSTS
- FAR OUTER PLANET ORBITER
- INTERPLANETARY TRAVEL

## INTRODUCTION AND BACKGROUND

### • PAST EXPERIENCE

NERVA/ROVER  
SNAP 10A  
NUCLEAR/THERMIONICS  
SPACE RANKINE AND BRAYTON  
SOLAR DYNAMIC CONCENTRATOR AND RECEIVER  
RTG - 22 U.S. SPACECRAFT

### • PRESENT

GPHS RTG  
GALILEO  
ULYSSES

### • FUTURE

MOD RTG  
DIPS  
SOLARDYNAMICS  
SP-100 THERMOELECTRICS  
SP-100 STIRLING  
NUCLEAR/THERMIONICS

### • DREAMS

NUCLEAR FUSION  
ANTI-MATTER  
ETC.

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamic and Nuclear Power Systems

*Dynamic and Nuclear Systems*

Dr. John M. Smith  
NASA Lewis Research Center

**TECHNOLOGY NEEDS:**

• **NUCLEAR**

- HIGH POWER/ENERGY
- LONG LIFE/HIGH RELIABILITY
- AUTONOMOUS OPERATION
- 100% SAFE

• **DYNAMIC POWER CONVERSION SYSTEMS**

- 2 PHASE FLOW - RANKINE
- START-UP/SHUT DOWN/RESTART - RANKINE
- GAS BEARINGS - BRAYTON AND STIRLING
- COMPACT/LIGHTWEIGHT RADIATORS

• **SOLAR DYNAMIC SYSTEMS**

- LIGHTWEIGHT, HIGH HEAT CAPACITY, HIGH THERMAL CONDUCTIVITY THERMAL ENERGY STORAGE (TES) SYSTEMS
- SPACE VERIFICATION OF TES VOID THEORY AND GROUND EXPERIMENTS
- THERMAL CONTROL AND ENVIRONMENTAL PROTECTION COATINGS FOR CONCENTRATOR SURFACES

• **POWER MANAGEMENT AND DISTRIBUTION**

- HIGH POWER/VOLTAGE
- HIGH TEMPERATURE
- RADIATION RESISTANT
- FAULT TOLERANT/AUTONOMOUS

• **MATERIALS**

- TESTING IN COMBINED SPACE ENVIRONMENT
- SURFACE COATINGS/MODIFICATION FOR HIGH EMISSIVITY RADIATORS
- REFRACTORY METAL DATA BASE FOR HIGH TEMPERATURE DYNAMIC AND NUCLEAR SYSTEMS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamic and Nuclear Power Systems

*Dynamic and Nuclear Systems*

Dr. John M. Smith  
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**SUMMARY AND RECOMMENDATIONS**

- **DYNAMIC AND NUCLEAR SYSTEMS REQUIRE IN-SPACE EXPERIMENTS**  
  
BASIC RESEARCH TO PROVIDE DESIGN DATA  
  
COMPONENT TESTING TO VERIFY DESIGN DATA
- **IN-SPACE EXPERIMENTS PROVIDE ONLY TRUE TEST OF COMBINED SPACE ENVIRONMENTAL EFFECTS**

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

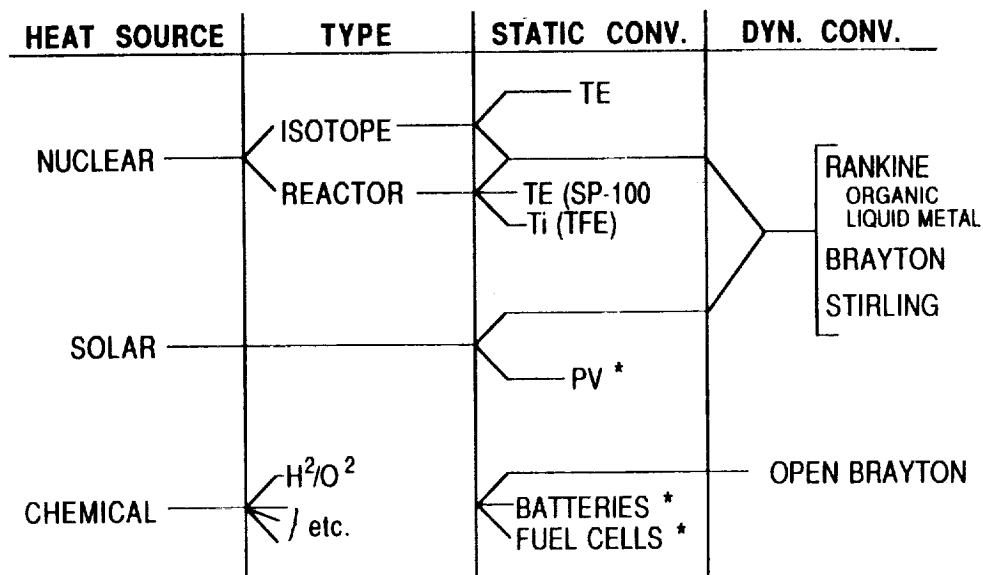
Theme 3 of 8

3.1 Dynamic and Nuclear Power Systems

***Dynamic and Nuclear Systems***

Dr. John M. Smith  
NASA Lewis Research Center

**DYNAMIC AND NUCLEAR SPACE POWER SYSTEMS**



\* NOT CONSIDERED AS PART OF DYNAMIC AND NUCLEAR SYSTEM WORKSHOP

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamics and Nuclear Power Systems

***Dynamic & Nuclear Power Systems***

Dr. J.S. Armljo  
General Electric Astro Space Division

**TECHNOLOGY NEEDS**

● **REACTORS**

- HIGH TEMP. TRANSIENT FUEL FOR BURST POWER & PROPULSION
- WELL CHARACTERIZED HIGH TEMP./STRENGTH MATERIALS
- MATERIAL FABRICATION & JOINING

● **SHEILDING**

- LOW MASS SHIELD MATERIAL/CONFIGURATIONS
- TEMPERATURE TOLERANT SHIELD MATERIALS
- IMPROVED MCNP CODES/EXPERIMENT VALIDATION

● **CONVERSION**

- IMPROVED PERFORMANCE PASSIVE CONVERSION
- RELIABLE SPACE QUALIFIED DYNAMIC CONVERSION
- HIGH TEMP. MATERIALS, BEARINGS/SEALS
- SPACECRAFT COMPATIBLE - JITTER, EFFLUENTS, ETC.

● **STRUCTURE**

- FABRICATION & JOINING IN MICRO/ZERO GRAVITY

● **THERMAL MANAGEMENT**

- LOW MASS RADIATORS
- THERMAL COATINGS
- LOW MASS SURVIVABILITY TECHNIQUES
- FAULT TOLERANT - SELF HEALING STRUCTURES
- LOW COST/HIGH PERFORMANCE HEAT PIPES

● **INSTRUMENTATION & CONTROL**

- SUPER RAD HARD ELECTRONICS (INSTR. & COMMUNICATIONS)
- RELIABLE FAULT TOLERANT ARCHITECTURE
- HYBRID PACKAGING VLSI COMPONENTS
- LONG LIFE HIGH TEMP/RAD TOLERANT SENSORS

● **POWER MANAGEMENT & DISTRIBUTION**

- HIGH PERFORMANCE, LOW MASS HARDWARE
- HIGH VOLTAGE TRANSFORMATION, INSULATION & DISTRIBUTION

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.1 Dynamics and Nuclear Power Systems**

***Dynamic & Nuclear Power Systems***

Dr. J.S. Armijo  
General Electric Astro Space Division

**IN-SPACE EXPERIMENTS**

APPLICATION	EXPERIMENT	TIME FRAME
REACTOR COOLANT LOOP	● HE GAS COLLECTION AND RETENTION IN LIQUID METAL COOLANTS IN MICRO AND ZERO GRAVITY	'92+
REACTOR COOLANT LOOP CONVERSION	● TWO PHASE SOLID/LIQUID PUMPING, FLOW AND SEPARATION AND MICRO ZERO GRAVITY	'92+
REACTOR COOLANT LOOP CONVERSION	● TWO PHASE LIQUID/GAS SEPARATION AND GAS ACCUMULATION IN WORKING FLUIDS AND COOLANT LOOPS	'92+
REACTOR COOLANT LOOP	● GAS BUBBLE NUCLEATION AND GROWTH PHENOMENA IN LIQUID METALS	'92+
REACTOR COOLANT LOOP CONVERSION	● FREEZE/THAW OF LIQUID METALS IN-SPACE, INCLUDING VOID FORMATION AND DISTRIBUTION	'92+
STRUCTURE MATERIALS	● ATOMIC OXYGEN CORROSION RATES OF HIGH TEMP STRUCTURAL MATERIALS IN SPACE ENVIRONMENT	'92+
STRUCTURE MATERIALS FABRICATION OPERATIONS	● MICRO GRAVITY/ZERO GRAVITY EFFECTS ON WELDING AND JOINING	'94+
OPERATIONS	● MAINTENANCE & SERVICING OF POWER SYSTEMS BY ROBOTICS IN REMOTE MICRO-ZERO GRAVITY SPACE & PLANETARY ENVIRONMENTS	'94+

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.1 Dynamics and Nuclear Power Systems

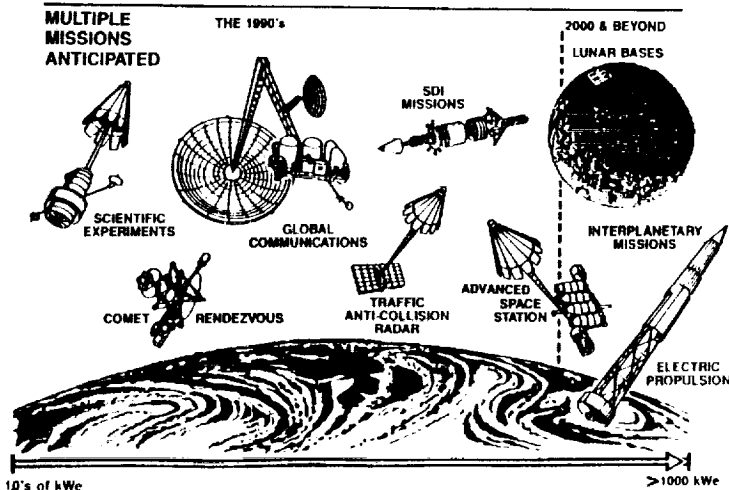
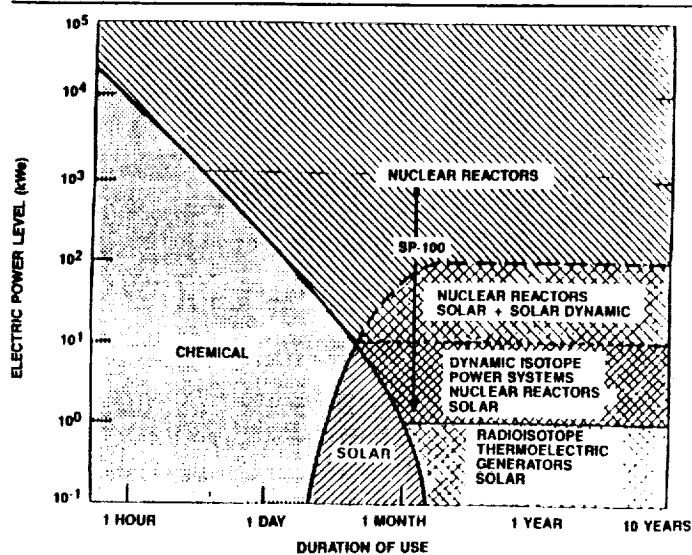
#### Dynamic & Nuclear Power Systems

Dr. J.S. Armijo  
General Electric Astro Space Division

#### SUMMARY/RECOMMENDATIONS

- SPACE POWER IS A PRECIOUS COMMODITY
- HIGH POWER SIGNIFICANTLY ENHANCES AND ENABLES FUTURE SPACE MISSIONS
- SPACE EXPERIMENTS WILL PROVIDE ASSURANCE OF HIGH TEMPERATURE LIQUID METAL COOLANT, CONVERSION WORKING FLUID & MATERIAL PERFORMANCE AND LIFETIME.
- EXPERIMENTS ARE COMPATIBLE WITH EARLY TO MID '90 STS OPERATIONS

#### QUALITATIVE RANGE OF APPLICABILITY OF VARIOUS SPACE POWER SYSTEMS



Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamics and Nuclear Power Systems

***Dynamic & Nuclear Systems***

**Prof. Mohamed S. El-Genk**

University of New Mexico, Institute for Space Nuclear Power Studies

**INTRODUCTION/BACKGROUND**

**SPACE POWER SYSTEM REQUIREMENTS**

- LONG LIFE (UP TO 10 YEARS)
- HIGH RELIABILITY ( > 0.95 )
- HIGH SPECIFIC POWER (UP TO 100 We/kg)
- SAFETY ( LAUNCH, IN-FLIGHT, IN-ORBIT, AND END OF MISSION DISPOSAL)
- MODULARITY AND SCALABILITY
- LOAD - FOLLOWING/AUTONOMOUS OPERATION

**ADVANCED TECHNOLOGY NEEDS**

- HIGH TEMPERATURE MATERIALS
- EFFICIENT AND RELIABLE CONVERTORS (STIRLING, THERMOELECTRICS, THERMIONIC, BRAYTON, RANKINE
- INSTRUMENTATION/POWER CONDITIONING/HARD ELECTRONICS
- ROBOTICS, SIMULATION, FAULT DETECTION AND AUTONOMY

**MISSION APPLICATIONS**

- ORBITING PLATFORMS
- SPACE STATION
- LUNAR MISSION SUPPORT APPLICATIONS
- MARS MISSION SUPPORT APPLICATIONS
- SPACE AND LUNAR COMMERCIALIZATION ACTIVITIES
- PLANETARY EXPLORATION SPACECRAFT
- ORBITAL OPERATIONS SUPPORT VEHICLES

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamics and Nuclear Power Systems

*Dynamic & Nuclear Systems*

Prof. Mohamed S. El-Genk

University of New Mexico, Institute for Space Nuclear Power Studies

**TECHNOLOGY NEEDS**

• **THERMAL MANAGEMENT**

- TWO-PHASE FLOW IN MICROGRAVITY
- TWO-PHASE SEPARATION IN MICROGRAVITY
- CONDENSATION AND SEPARATION OF NON-CONDENSIBLE GASES
- BOILING PHENOMINA CRITICAL HEAT FLUX/BUBBLE NUCLEATION
- THAW AND RETHAW IN ORBIT OF LIQUID METAL SYSTEMS
- CRITICAL FLOW, SURFACE TENSION AND WETTING ANGLE IN-ORBIT
- INTERFACIAL PHENOMINA (LIQUID/LIQUID AND LIQUID/SOLID)
- HEAT PIPES TRANSIENT OPERATION AND STARTUP FROM FROZEN STATE

• **MATERIALS**

- COMPATIBILITY WITH ADVANCED AND REFRACTORY-METAL ALLOYS
- SELF-DIFFUSION/SELF-WELDING
- ADVANCED RADIATOR FABRICS/HIGH TEMPERATURE COMPOSITS
- THERMAL AND ELECTRICAL INSULATION
- EFFECT OF CHARGED PARTICLES (ele & pro) ON OPTICAL PROPERTIES OF SPACECRAFT STRUCTURE MATERIALS
- EFFECTS OF ATOMIC OXYGEN ON POWER CABLES, INSULATION AND STRUCTURE MATERIALS
- LUNAR AND MARTIN SHEILDING MATERIALS

**OPERATION AND SAFETY**

- AUTOMATION AND AUTONOMY
- AUTOMATION AND CONTROL
- RELIABILITY
- IN-ORBIT THAW AND RETHAW
- CRITICAL FLOW AND INTERFACIAL PHENOMENA
- SURVIVABILITY
- TEMPERATURE, PRESSURE, AND RADIATION SENSORS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamics and Nuclear Power Systems

***Dynamic & Nuclear Systems***

**Prof. Mohamed S. El-Genk**

University of New Mexico, Institute for Space Nuclear Power Studies

**IN-SPACE EXPERIMENTS NEEDS/VOIDS**

**PROOF OF PRINCIPLE EXPERIMENTS (BASIC RESEARCH)**

- TWO-PHASE AND TWO-COMPONENT FLOW EXPERIMENTS
- CHANGE-OF-PHASE (MELTING/FREEZING) OF PURE LIQUIDS AND LIQUID-GAS MIXTURES
- INTERACTION OF ATOMIC OXYGEN AND CHARGED PARTICLES WITH THERMAL AND ELECTRIC INSULATION, CABLES, STRUCTURE, RADIATOR SURFACE
- INTERFACIAL PHENOMENA (WETTING, SURFACE AREA, INTERFACE CHARACTERIZATION
- SELF DIFFUSION/ SELF WELDING AND MATERIAL COMPATIBILITY
- STARTUP OF HIGH TEMPERATURE HEAT PIPE FROM FROZEN STATE
- ADVANCED HIGH TEMPERATURE ALLOYS INVOLVING HEAVY/LIGHT ELEMENT
- BOILING AND CONDENSATION OF PURE LIQUIDS/LIQUID MIXTURES
- CRITICAL FLOW EXPERIMENTS

**CONCEPT VERIFICATION EXPERIMENTS OF DEVICES/COMPONENTS**

- GAS/VAPOR SEPARATORS
- ADVANCED INSTRUMENTATION/ELECTRONIC DEVICES
- THAW AND RETHAW OF LIQUID METAL LOOPS
- ADVANCE RADIATOR CONCEPTS
- FAULT DETECTION/AUTONOMY SIMULATIONS
- ROTATING DEVICES ( NUCLEAR REACTOR CONTROL SYSTEM, STIRLING ENGINE, BRAYTON TURBO-ALTERNATOR, AND RANKINE)
- LOSS-OF-FLOW SIMULATION

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.1 Dynamics and Nuclear Power Systems

***Dynamic & Nuclear Systems***

**Prof. Mohamed S. El-Genk**

University of New Mexico, Institute for Space Nuclear Power Studies

**SUMMARY/RECOMMENDATIONS**

**SPACE POWER SYSTEMS DEVELOPMENT AND ADVANCED  
TECHNOLOGY NEEDS ARE BEST MET BY:**

- BASIC RESEARCH AND PROOF OF PRINCIPLE  
IN-SPACE EXPERIMENTS
- CONCEPT VERIFICATION IN-SPACE EXPERIMENTS OF  
DEVICE/COMPONENTS

**IN-SPACE EXPERIMENTS ARE NECESSARY TO THE  
SUCCESS OF FUTURE MISSIONS INCLUDING:**

- MARS AND LUNAR MISSIONS
- SPACE COMMERCIALIZATION

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.2 Conventional Power Systems

#### *Conventional Power Systems*

Dr. Karl A. Faymon  
NASA Lewis Research Center, Power Technology Division

## INTRODUCTION/BACKGROUND

- SPACE POWER SYSTEMS OF THE PAST:
  - Low power-low voltage DC systems
  - High specific mass/high cost per Kw.
- PRESENT DAY SPACE POWER SYSTEMS:
  - Improved specific mass
  - Still low power-low voltage DC systems
  - Cost improvements have been accomplished
- TO ENSURE A VIABLE SPACE PROGRAM, POWER SYSTEMS OF THE FUTURE MUST HAVE GREATLY IMPROVED ATTRIBUTES:
  - High power-high voltage AC systems
  - Significant reductions in weight
  - Significant reductions in costs

## MISSION APPLICATIONS

- Planetary exploration spacecraft
- Earth surveillance satellites
- Earth resource satellites
- Communication satellites
- Space station
- Orbiting platforms
- Lunar mission support applications
- Mars mission support applications
- Orbital operations support vehicles
- Cis-lunar transportation vehicles
- Space commercialization activities

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.2 Conventional Power Systems**

***Conventional Power Systems***

**Dr. Karl A. Faymon**

NASA Lewis Research Center, Power Technology Division

**TECHNOLOGY NEEDS/CRITICAL TECHNOLOGIES**

● **SOLAR PHOTOVOLTAIC CELLS**

- High efficiency/lightweight solar cells
- Radiation tolerant cells
- Lightweight solar arrays
  - Deployable
  - Stowable
- Refractive concentrator development

● **HIGH ENERGY DENSITY STORAGE SYSTEMS**

- Advanced batteries
- Regenerative fuel cells
- Inertial energy storage
- Superconducting magnetic energy storage

● **POWER MANAGEMENT AND DISTRIBUTION SYSTEMS**

- High power/high voltage systems
- High frequency AC components and devices
- Fault tolerant power systems and components
- Autonomous power systems operation

● **MATERIALS**

- Materials for high power-high voltage systems
  - Insulators
  - Conductors
  - Thermal control materials
- Materials compatibility with operating environment

● **ENVIRONMENTAL INTERACTIONS**

- Design criteria for power system space operating environment comparability
  - High voltage operation
  - Spacecraft charging/discharging phenomena
- Design criteria for power system planetary environment compatibility
  - Lunar surface operation
  - Martian atmosphere environment

**IN-SPACE EXPERIMENTS NEEDS/VOIDS**

Power Technology Development Experiments Can Be Put Into The Following Three Broad Categories:

- I. Proof of principle experiments (Basic research)
- II. Concept verification experiments of devices/components
- III. Design/operational readiness verification tests of systems in space

The Space Power In-Space Experiments program is directed toward category I and II experiments:

- In support of the OAST Base Research and Technology Program
- To support the Civil Space Technology Initiative
- To support the Pathfinder Program

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## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.2 Conventional Power Systems

#### Conventional Power Systems

Dr. Karl A. Faymon

NASA Lewis Research Center, Power Technology Division

#### IN-SPACE EXPERIMENTS NEEDS/VOIDS

ELEMENTS	SPACE ENERGY CONVERSION R&T						REQUIREMENTS/GOALS	IN SPACE EXPERIMENTS SUPPORT
	87	89	90	91	92	93		
PHOTOVOLTAIC ENERGY CONVERSION		ADVANCED PV CELL TECH.					<ul style="list-style-type: none"> <li>● PROVIDE TECH. BASE FOR HIGH POWER TO WEIGHT, LONG LIFE PV ARRAYS FOR LEO, GEO, AND SOLAR EXPLORATION MISSIONS.</li> </ul>	<ul style="list-style-type: none"> <li>▼ 1990: Short term (hours-days) exposure at LEO for calibration of space solar cells.</li> <li>▼ 1994: Long term (years) exposure in low earth, polar, and mid-altitude orbits to determine performance of new cells, blankets and concentrator elements in the actual space environment.</li> </ul>
CHEMICAL ENERGY CONVERSION		PRIMARY-SECONDARY BATT'S					<ul style="list-style-type: none"> <li>● ENHANCE UNDERSTANDING OF EC TECHNOLOGIES</li> <li>● HIGH ENERGY DENS. LONG LIFE PRIMARY AND SECONDARY BATTERIES AND PRIM. AND RECHG. FUEL CELLS.</li> <li>● DEVELOP AND EVAL. ADVANCED CONCEPTS FOR SPACE EC SYSTEMS.</li> </ul>	<ul style="list-style-type: none"> <li>▼ 1990: Experiments to compile a technology data base on electrochemical phenomena:               <ul style="list-style-type: none"> <li>- Bubble/droplet formation on electrodes.</li> <li>- Converting forces kinetics, two phase flow, liquid and gas management, current effects in electrochemical systems in micro-gravity.</li> </ul> </li> <li>▼ 1992: Verify the performance of advanced EC systems such as NaS, batteries, H<sub>2</sub>O<sub>2</sub> regen. fuel cells, H<sub>2</sub>BR fuel cells in micro-gravity.</li> </ul>
POWER MANAGEMENT		HI VOLT. HI POW. SYST'S					<ul style="list-style-type: none"> <li>● PROVIDE TECH. BASE IN ANALYTICAL AND COMPONENT TECHNOL. NECESSARY FOR POWER MANAGEMENT AND DISTRIBUTION OF POWER ON FUTURE NASA SPACE MISSIONS</li> </ul>	<ul style="list-style-type: none"> <li>▼ 1990: Demonstrate in-space performance of passive high thermal conductivity power system heat rejection techniques utilizing graphite fiber composite materials.</li> </ul>
POWER SYSTEM MATERIALS		SOL. ARRAY BLANKET MAT'S					<ul style="list-style-type: none"> <li>● PROVIDE TECHNOLOGY FOR LONG LIFE-HIGH PERFORMANCE POWER SYSTEM MATERIALS.</li> </ul>	<ul style="list-style-type: none"> <li>▼ 1990: Provide in-space verification of ground simulation systems for LEO atomic oxygen durability testing.</li> </ul>
SPACE ENVIRONMENTAL INTERACT'S		SPASAC LEO DEVELOPMENT					<ul style="list-style-type: none"> <li>● PROVIDE MODELING AND ANALYSIS CAPABILITY TO PERFORM DESIGN OF ENVIRONMENTALLY COMPATIBLE SPACE SYSTEMS.</li> </ul>	<ul style="list-style-type: none"> <li>▼ 1990: Plasma interaction experiments with solar arrays.</li> <li>▼ 1992: Ion thruster efflux characterization.</li> <li>▼ 1993: In space verification of high voltage AC power system interactions.</li> <li>▼ 2000: More surface high-voltage effects. (RAP: 10/15/88: 310.)</li> </ul>

NOTES: ▲ R&T PROGRAM MILESTONES.

(Experiment dates shown are definition phase start dates).

(RAP: 10/15/88: 310.)

#### IN-SPACE EXPERIMENTS NEEDS/VOIDS

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
------	------	------	------	------	------	------	------	------	------	------

- SHORT TERM EXPOSURE TESTS OF PV CELLS
- EXPERIMENTS TO COMPILE DATA ON ELECTROCHEMICAL PHENOMENA
- SHORT TERM MATERIALS TESTING
- ION THRUSTER EFFLUX CHARACTERIZATION

- DEVELOPMENT EXPERIMENTS ON ADVANCED BATTERIES
- PLASMA INTERACTION EXPERIMENTS FOR SOLAR ARRAYS
- IN-SPACE PERFORMANCE OF HEAT REJECTION TECHNIQUES

- LONG TERM EXPOSURE TESTS OF NEW SOLAR CELLS, BLANKETS, ARRAYS, ETC.
- LONG TERM EXPOSURE TESTING OF POWER SYSTEM MATERIALS

- IN-SPACE VERIFICATION OF HIGH-VOLTAGE POWER SYSTEMS INTERACTIONS-OPERATIONS

PHOTOVOLTAICS  
HIGH ENERGY DENSITY STORAGE  
POWER MANAGEMENT AND DISTRIBUTION  
ENVIRONMENTAL INTERACTIONS  
MATERIALS FOR POWER SYSTEMS

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.2 Conventional Power Systems

#### *Conventional Power Systems*

**Stephen R. Peck**  
General Electric, Astro Space Division

#### *High Priority Technology Objectives*

##### • Better Batteries

- Lower weight (higher w-hr/lb)
- Higher capacity (up to about 200 A-hr)
- Longer activated shelf life (cost and schedule issue)
- Less expensive
- Improved volume efficiency
- Improved thermal design/thermal interface (esp. for IPV  $\text{NiH}_2$ )
- Lower temperature sensitivity
  - Higher operating temperature range
- Most promising near-term technologies
  - CPV  $\text{NiH}_2$  - Low cost and high performance
  - NaS - high performance

##### • High voltage power distribution switch gear

- 50, 100, 200 VDC operation
- 1, 2, 5, 10, 20, 50, 100 ADC operation
- Switches with "relay-like" characteristics
  - High efficiency (> 99.9%)
  - Permanent memory
  - High noise immunity, command/power ground isolation
  - Light weight
  - High reliability
  - Low cost
  - High surge-carrying capability

##### • Fuses

- High reliability, hermetically sealed
- Sturdy, lightweight

##### • Better Solar Cells/Arrays

- Higher efficiency
- Lower weight (thin cells, spray-on cover glass)
- Improved radiation hardness
  - Eliminate need for cover glass
- UV tolerant adhesive and cells
- Lower cost
- Built-in reverse voltage protection
- Improved interconnections
- Concentrator technologies (especially for laser hardening)

##### • Capacitors

- 100, 200, 400 VDC operation
- 1, 10, 20, 50, 100 microfarads
- Low ESR, high AC current rating
- Volumetrically efficient
- High resonant frequency
- Light weight
- Fail-safe (ie. no permanent short circuit failure mode)

##### • Radiation Hardened Power MOSFETs

- Higher power ratings
- Prompt response hard (X-ray)
- Single event upset hard (cosmic ray)

##### • Combined Technology Power Control Building Blocks

- Analog, digital, and power devices in standard building block packages (power hybrids)
  - Digital input signal, high power switch output.
- Could be part of enabling technology for resonant and quasi-resonant converters with promise of > 2:1 power density improvement

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.2 Conventional Power Systems

#### *Conventional Power Systems*

**Stephen R. Peck**  
General Electric, Astro Space Division

### *In-Space Experiments Needs (Near-Term)*

- Qualification of most power systems equipment can be satisfactorily accomplished without in-space demonstration.
  - Exception - Equipment possibly sensitive to micro-gravity such as batteries.
- Biggest need for flight experiments is to better define the characteristics of certain space environments. Better environment models will permit improved performance analyses/predictions and thus better designs.
  - Space plasma
    - Effect on high-voltage solar arrays
    - ESD
  - Atomic oxygen
  - Charged particle environment in mid-altitude orbits
    - Possible effect on UV degradation

### *Suggested In-Space Experiment*

#### *Contamination, U-V and Charged Particle Induced Solar Array Effects*

**Concerns** Unresolved degradation of solar arrays due to space UV/charged particle radiation effects; Unresolved UV/charge particle degradation on advanced cell types.

**Objectives** Establish design criteria for UV/charge particle radiation effects on contamination; Establish design criteria for UV/charged particle radiation effects on advanced cell types.

**Variables** Orbit charged particle environment, contamination type and amount, solar cell type/configuration, solar array components other than solar cells (covers, adhesives, etc.)

**Approach** Test articles flown would be designed to test for UV, radiation and contaminant degradation. Various thickness of coverglass would be used to factor radiation, etc. Entire I-V curves would be measured periodically.

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.2 Conventional Power Systems

***Conventional Power Systems***

**Stephen R. Peck**  
General Electric, Astro Space Division

***Suggested In-Space Experiment***

***Plasma Induced Solar Array Effects***

- Concerns** Degradation of solar cells/solar arrays due to the plasma environment.
- Objectives** Establish design criteria for advanced array designs operating in plasma environments.
- Variables** Orbit/plasma environment, solar array operating voltage, solar cell type/configuration, solar array components other than solar cells (covers, adhesives, insulators, etc.), solar array layout.
- Approach** Test articles to be flown would be designed to include as many advanced concepts as practical.

Theme 3 of 8

## POWER SYSTEMS & THERMAL MANAGEMENT

Theme 3 of 8

### 3.2 Conventional Power Systems

#### *Conventional Power Systems*

**R.F. Askew**

Auburn University, Center for Commercial Development of Space Power, Space Power Institute

#### OVERVIEW

- **SPACE POWER SYSTEMS**
  - MULTIDISCIPLINARY TECHNOLOGY REQUIRED
  - SYSTEM ADVANCES ARE INCREMENTAL
  - UNIQUE POWER-ENVIRONMENT COUPLING
- **CURRENT STATE-OF-ART**
  - A FEW KILOWATTS
  - LOW VOLTAGE-HIGH CURRENT
- **FUTURE NEEDS**
  - HUNDREDS OF KILOWATTS-MEGAWATTS
  - EXTREME RELIABILITY/AUTONOMY
  - MINIMUM REDUNDANCY/MAXIMUM SELF HEALING
  - HIGHER VOLTAGE OPERATIONS
  - BROAD PARAMETER RANGE DATABASE
- **UNIQUE UNIVERSITY ROLE**
  - ALL DISCIPLINES REPRESENTED AT MAJOR UNIVERSITY
  - DIFFERENCE BETWEEN SOA AND PROJECTED NEEDS MAKE "FIRST PRINCIPLES" APPROACHES ATTRACTIVE
  - PARALLEL EFFORTS ARE COST EFFECTIVE
  - EDUCATION OF SPACE POWER ENGINEERS AND SCIENTISTS

#### MISSION APPLICATIONS

- PLANETARY EXPLORATION SPACECRAFT
- EARTH SURVEILLANCE SATELLITES
- EARTH RESOURCE SATELLITES
- COMMUNICATION SATELLITES
- SPACE STATION
- ORBITING PLATFORMS
- LUNAR MISSION SUPPORT APPLICATIONS
- MARS MISSION SUPPORT APPLICATIONS
- ORBITAL OPERATIONS SUPPORT VEHICLES
- CIS-LUNAR TRANSPORTATION VEHICLES
- SPACE COMMERCIALIZATION ACTIVITIES

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.2 Conventional Power Systems**

***Conventional Power Systems***

**R.F. Askew**

Auburn University, Center for Commercial Development of Space Power, Space Power Institute

**NEEDED RESEARCH FOCUS TOPICS**

- **SOLAR PHOTOVOLTAIC CELLS**
  - METAL/SEMI-CONDUCTOR/INSULATOR INTERFACE PHENOMENA
  - QUANTUM WELLS/GRADED BAND GAP DEVICES/SUPER LATTICE
  - DEGRADATION MECHANISMS
  - MULTISTIMULUS SPACE EFFECTS
- **HIGH ENERGY DENSITY STORAGE SYSTEMS**
  - FAILURE MECHANISMS
  - ELECTRODE PHENOMENA
  - OPERATION IN RADIATION ENVIRONMENT
  - VACUUM OPERATION
  - SAFETY ISSUES
  - OPERATION IN 0 "g"
- **POWER MANAGEMENT AND DISTRIBUTION SYSTEMS**
  - INTEGRATION OF AI/EXPERT SYSTEM INTO POWER/THERMAL MANAGEMENT
  - EFFECTS OF ENVIRONMENT INDUCED SYSTEM ERRORS
  - VOTING LOGIC IN AI
  - SELF HEALING COMPONENTS
  - FAULT MANAGEMENT TECHNIQUES
  - ADVANCED DIAGNOSTIC SUITES/NEW SENSORS
  - DISTRIBUTION SYSTEM/ENVIRONMENTAL INTERACTIONS--EFFECTS & LIMITS
  - POWER (V-I CHARACTERISTICS)/THERMAL MANAGEMENT TRADE OFF IMPLICATIONS
- **MATERIALS**
  - NEW CLASSES OPTIMIZED FOR LONG TERM SPACE EXPOSURE
  - DETAILED UNDERSTANDING OF MATERIALS RESPONSE
  - SELF HEALING MATERIALS/COATINGS
  - CONTAMINATION MECHANISMS
- **ENVIRONMENTAL INTERACTIONS**
  - POWER/PLATFORM/ENVIRONMENT SYNERGISM
  - LONG TERM EVOLUTION OF LOCAL ENVIRONMENT
  - LIMITS IMPOSED ON POWER SYSTEM PARAMETER SPACE
- **SIMULATION**
  - THEORY & MODELING
  - ADVANCED MULTISTIMULUS FACILITIES
  - ACCELERATED AGING METHODOLOGY
  - BENCHMARK SPACE EXPERIMENTS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.2 Conventional Power Systems**

***Conventional Power Systems***

**R.F. Askew**

Auburn University, Center for Commercial Development of Space Power, Space Power Institute

**IN-SPACE EXPERIMENTAL NEEDS**

EXPERIMENT	ISSUES	FOCUS
Dynamics of high current arcs in 0 "g"	Gas switch operation. Fault management.	Effects of 0 "g" on switch stability/reliability. Control of arc faults in contaminated space environments.
0 "g" liquid/solid phase change dynamics.	Thermal energy storage.	Two phase component separation. Effects on thermal conductivity.
Spatial and temporal evolution of space debris.	Surface flashover. Corona discharges.	Insulation degradation debris migration in electrical/magnetic fields.

**IN-SPACE EXPERIMENTS NEEDS/VOIDS**

- ACCURATE CHARACTERIZATION OF SPACE ENVIRONMENT & ITS EVOLUTION
- VERIFY SIMULATION & MODELING OF SPACE ENVIRONMENT
- ACCURATE DETERMINATION OF PLATFORM ROLE IN LONG TERM EVOLUTION OF LOCAL SPACE ENVIRONMENT
- BENCHMARK EXPOSURE (LDEF) TO DETERMINE ADEQUACY OF SIMULATION OF LONG TERM EXPOSURE
- ELECTRICAL CHARACTERIZATION OF SPACE ENVIRONMENT
- LONG TERM CONTROLLABLE MICROGRAVITY LABORATORY

**CRITICAL TECHNOLOGIES**

1. HIGH EFFICIENCY SOLAR CELL TECHNOLOGY
2. HIGH ENERGY DENSITY ENERGY STORAGE SYSTEMS
3. NEW MATERIALS TECHNOLOGY SPECIFICALLY OPTIMIZED FOR LONG TERM SPACE APPLICATIONS
4. ADVANCED DIAGNOSTIC TECHNIQUES EMPLOYING AI/EXPERT SYSTEMS
5. FAULT TOLERANT POWER SYSTEMS
6. MULTISTIMULUS SPACE SIMULATION FACILITIES
7. HIGH EFFICIENCY THERMAL MANAGEMENT TECHNOLOGY
8. HIGH EFFICIENCY HIGH TEMPERATURE ELECTRONICS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**  
3.3 Thermal Management

Theme 3 of 8

***Government View: Spacecraft Thermal Management Requirements & Technology Needs***

**Dr. Tom Mahefkey**  
Air Force Wright Aeronautical Labs, Aerospace Power Division

**PRELIMINARY REMARKS**

- THERE ARE SIGNIFICANT DIFFERENCES AMONG SPONSORING AGENCIES RELATED TO MISSIONS, GOALS, OBJECTIVES, POLICIES, AND ATTITUDES...
- THERE IS THUS NO SINGLE OVERALL GOVERNMENT VIEWPOINT RELATED TO TECHNOLOGY NEEDS, R&D PRIORITIES, INVESTMENT STRATEGIES, AND PROGRAMMATIC POLICIES
- THIS PRESENTATION ADDRESSES ONLY THE MISSION IMPLIED TECHNOLOGY NEEDS AND LIKELY "NATIONAL" DIRECTION IN SPACECRAFT THERMAL MANAGEMENT R&D

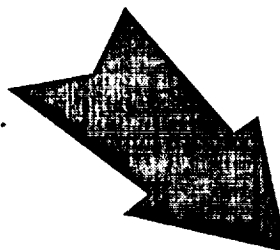
**THE NATIONS SPACE MISSION SET**

**NASA MISSIONS**

- Δ INTERPLANETARY/DEEP SPACE SCIENCE PLATFORMS, MANNED MISSIONS
- Δ EARTH RESOURCES/NEAR EARTH SCIENCE PLATFORMS
- Δ COMMUNICATIONS
- Δ SPACE STATION....SCIENCE PLATFORM, SPACE MAN'F, LAUNCH PLATFORM
- Δ LUNAR BASE
- Δ NASP

**DOD MISSIONS**

- Δ NAVIGATION, METEOROLOGY....
- Δ SURVEILLANCE, EARLY WARNING....
- Δ COMMUNICATIONS
- Δ DEFENSE FROM SPACE (SDI)....
- Δ NASP, HLLV, ALS



**KEY DIFFERENCES**

- MILITARY MISSIONS ALL NEAR EARTH
- MILITARY MISSIONS MUST BE SURVIVABLE
- OPERATING ORBITS, MASS TO ORBIT
- MANNED VS. UNMANNED
- SPACE MAINTAINABLE VS. AUTONOMOUS

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Government View: Spacecraft Thermal Management Requirements & Technology Needs***

**Dr. Tom Mahefkey**

Air Force Wright Aeronautical Labs, Aerospace Power Division

**NASA/DOD THERMAL MANAGEMENT NEEDS CONTRASTED**

	<b><u>NASA</u></b>	<b><u>DOD</u></b>
<input type="checkbox"/> HEAT ACQUISITION <ul style="list-style-type: none"> <li>• 10-100K</li> </ul>	<ul style="list-style-type: none"> <li>✓ IR SENSORS</li> <li>✓ PROPELLANT DEPOT, DELIVERY</li> </ul>	<ul style="list-style-type: none"> <li>✓ SIMILAR SENSORS</li> <li>✓ CRYO-COOLED DEW LOADS</li> <li>✓ HIGHER POWER, LOWER ALLOWABLE <math>\Delta T</math></li> </ul>
<ul style="list-style-type: none"> <li>• 300-400K</li> </ul>	<ul style="list-style-type: none"> <li>✓ MANNED HABITAT ECS</li> <li>✓ PAYLOAD ELECTRONICS COOLING</li> <li>✓ THERMAL BUS DISTRIBUTED LOADS</li> </ul>	<ul style="list-style-type: none"> <li>✓ PRIMARILY UNMANNED</li> <li>✓ LONG LIFE ELECTRONICS-DENSER PACKAGING, HIGHER FLUXES</li> <li>✓ DISCRETE AND DISTRIBUTED LOADS</li> </ul>
<ul style="list-style-type: none"> <li>• 600-2000K</li> </ul>	<ul style="list-style-type: none"> <li>✓ ENERGY CONVERSION DEVICE COOLING SOLAR DYNAMIC, SP-100 REACTOR</li> <li>✓ SPACE MANUFACTURING PROCESS HEAT</li> </ul>	<ul style="list-style-type: none"> <li>✓ BOTH BASELOAD AND BURST POWER COOLING</li> </ul>
<input type="checkbox"/> HEAT TRANSPORT	<ul style="list-style-type: none"> <li>✓ LEO MAINTAINABLE ALLOWED</li> <li>✓ COST VS. MASS-TO-ORBIT DRIVEN</li> <li>✓ PRIMARILY CLOSED CYCLE, STEADY STATE</li> <li>✓ TO 100 kW/100M REGIME</li> <li>✓ MICRO-G ENVIRONMENT</li> </ul>	<ul style="list-style-type: none"> <li>✓ AUTONOMY, LONG UNATTENDED LIFE</li> <li>✓ MASS-TO-ORBIT VS. COST DRIVEN</li> <li>✓ BOTH OPEN/CLOSED CYCLE, HIGH PEAK TO AVERAGE PROFILES</li> <li>✓ TO 100MW-100M REGIME</li> <li>✓ MACRO-G ENVIRONMENT</li> </ul>
<input type="checkbox"/> HEAT REJECTION	<ul style="list-style-type: none"> <li>✓ SPACE ERECTIBLE RADIATORS</li> <li>✓ LEO, INTERPLANETARY, LUNAR NATURAL ENVIRONMENT SURVIVABILITY</li> </ul>	<ul style="list-style-type: none"> <li>✓ DEPLOYABLE</li> <li>✓ LEO-GEO ORBIT, NATURAL AND MILITARY THREAT ENVIRONMENT</li> </ul>

**COMMON NASA/DOD R&D NEEDS- TWO-PHASE HEAT TRANSPORT**

- ☐ HIGH TRANSPORT CAPACITY HEAT PIPES....CRYOGENIC THROUGH LIQUID METAL TEMPERATURE REGIMES...SCALING VALIDITY FOR CAPILLARY LOOPS, SUBCOOLING SIMILARITY DEMONSTRATION
- ☐ STEADY STATE HEAT TRANSFER - EXPERIMENTAL DATA ON CO-CURRENT, COUNTER CURRENT HEAT AND MASS TRANSFER...AUGMENTATION EFFECTIVENESS
- ☐ UNSTEADY HEAT TRANSFER - FROZEN AND SUPERCRITICAL START-UP...MICRO TO MACRO "G" INFLUENCES ON PRIMING, DEPRIMING...VOID FORMATION IN T.E.S. FREEZING/MELTING...
- ☐ MASS TRANSFER - HEAT PUMP LUBRICANT/REFRIGERANT SEPARATION, LIQUID REACTANT DELIVERY, VAPOR VENTING SEPARATION
- ☐ MICRO/MACRO "G" FLOW STABILITY REGIMES - GAS COOLED REACTOR START-UP, EXPANDABLE VOLUME RADIATORS...TRANSIENT AND PERIODIC CRYO-COOLED LOAD COOLING...VIBRATIONALLY INDUCED INSTABILITY

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.3 Thermal Management

***Government View: Spacecraft Thermal Management Requirements & Technology Needs***

**Dr. Tom Mahefkey**

Air Force Wright Aeronautical Labs, Aerospace Power Division

**SUMMARY**

- THERE ARE SIGNIFICANT DIFFERENCES IN THE APPLICATIONS AND OPERATING REGIMES OF THERMAL MANAGEMENT TECHNOLOGIES FOR MILITARY AND CIVILIAN MISSIONS....
- THE BASIC TECHNOLOGIES/TECHNICAL DISCIPLINES ARE THE SAME...THE SPECIFIC MISSION NEEDS NECESSITATE CHARACTERIZING THE TECHNOLOGY OVER WIDER REGIMES OF PERFORMANCE...
- MILITARY MISSIONS ARE MORE STRONGLY DRIVEN BY PERFORMANCE, LIFE, AND RELIABILITY.....
- THE NEED FOR MICRO/MACRO "G" IN-SPACE PERFORMANCE VERIFICATION EXISTS FOR BOTH MILITARY AND CIVILIAN MISSIONS...SPECTRUM OF NEEDS RANGE FROM FUNDAMENTAL PHENOMENA CHARACTERIZATION \TO FLIGHT - READINESS VERIFACATION.....

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.3 Thermal Management

***Thermal Management: An Industry Viewpoint***

**Ted J. Kramer**

Boeing Aerospace, Thermal/Fluid/Mechanical Systems

**Introduction/Background**

- **Focus on zero "g" issues**
  - **Not simulated on earth**
  - **Large time constant effects**
- **Identified**
  - **Technology needs and voids**
  - **Experiments**
  - **Facilities**
- **Recommendations**

**Technology Needs**

- **Basic zero "g" phenomena**
  - **Evaporation/boiling**
  - **Condensation**
  - **Two-phase flow**
    - **Pressure drop**
    - **Flow regimes**
    - **Stability**
  - **Surface tension effects**
  - **Wet wall dryout**
  - **Diffusion controlled processes**
  - **Droplet dynamics**
- **Supports component optimization and acceptable design conservatism**
- **Component performance in zero "g"**
  - **Flow stability**
  - **Pressure drop**
  - **Heat transfer effectiveness**
  - **Isothermality**
  - **Priming**
  - **Freezing and recovery**
  - **Induced accelerations (maneuvering)**
- **Component candidates**
  - **Heat pipes**
  - **Evaporators**
  - **Condensers**
  - **Two-phase system components**
    - **Tee's**
    - **Valves**
    - **Pumps**
  - **Thermal storage**
  - **Accumulators/reservoirs**
  - **Instrumentation**
- **Supports subsystem and system optimization**

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.3 Thermal Management

***Thermal Management: An Industry Viewpoint***

**Ted J. Kramer**

Boeing Aerospace, Thermal/Fluid/Mechanical Systems

**In-Space Experimentation Needs/Voids**

- Two-phase heat transfer
- Two-phase flow
- Heat pipes
  - Liquid metal
  - Unusual geometry/size
  - Cryogenic
- Two-phase fluid storage/reservoir
- Thermal storage
- Capillary loops
- Two-phase loops
- Zero "g" and short term accelerations
- New facilities
  - Multi-use
  - Well-defined interfaces
  - Industry and academia inputs
- Two-phase fluid (NH<sub>3</sub>) test bed
- Cryogenic test bed
- High-temperature test bed
- Long term operation and exposure test bed

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Thermal Management Issues in Advanced Space Missions: University Viewpoint***

**Prof. Larry C. White**  
University of Houston, Department of Mechanical Engineering

**INTRODUCTION**

- **Thermal Management Required for:**
  - Inhabitants (Environment)
  - Spacecraft Systems
  - On Board Experiments
- **Thermal Management Includes:**
  - Heat Acquisition and Transport
  - Heat Rejection
  - System Integration
- **Single Phase Loops and Systems Suitable for Small Vehicles**
- **Two Phase Thermal Loops Are Capable of:**
  - Higher Transport Capabilities
  - Constant Temperature Performance
- **Problems Inherent in Two Phase Systems**
  - Working Fluids
  - Vapor and Condensate Removal
  - Liquid-Vapor Interfacial Behavior
  - Phase Distribution
- **Problems Inherent in Heat Rejection Systems**
  - Radiating Area per Unit Weight
  - Contact Resistance
  - Thermal Storage

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Thermal Management Issues in Advanced Space Missions: University Viewpoint***

**Prof. Larry C. White**

University of Houston, Department of Mechanical Engineering

**IN-SPACE EXPERIMENTATION: NEEDS/VOIDS**

● **Heat Acquisition and Transport, General**

- **Fundamental Physical Measurements Leading to Q and  $\Delta P$  Correlations (data limited to drop tower and aircraft trajectories)**
  - **Flow Rates**
  - **Temperatures**
  - **Pressure (Drops)**
  - **Heat Transfer Rates**
  - **Quality (Void Fraction)**
  - **Configuration**
- **Photographic Observations (data limited to aircraft trajectories)**
  - **Flow Patterns/Phase Distribution**
  - **Interfacial Dynamics**
  - **Secondary Flows**

● **Heat Acquisition and Transport, Specific Components**

**(Complete Data Void for Almost All of These Components)**

- **Tube Farms**
- **Condensers**
  - **Capillary Pumped**
  - **Shear Flow**
- **Evaporators**
  - **Swirl Flow**
  - **Monogroove**
- **Pumping Systems**
  - **Rotary Fluid Management Devices (Pilot Pump)**
- **Load/Flow Control Strategies**

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Thermal Management Issues in Advanced Space Missions: University Viewpoint***

**Prof. Larry C. White**

University of Houston, Department of Mechanical Engineering

**SUMMARY/RECOMMENDATIONS**

**NEAR TERM RECOMMENDATION**

- Develop a Comprehensive In-Space Test Program for Behavior of Multi-Phase Fluids
- Perform as much Preliminary Work as Possible in Earth Labs, Centrifuges, Drop Towers, and Aircraft

**LONG TERM RECOMMENDATIONS**

- Testing of Advanced Radiators
- In-Space Testing of Heat Pumps
- Testing of Thermal Storage Systems

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Power Systems & Thermal Management Critical Technology Requirements***

**Roy McIntosh**  
NASA Goddard Space Flight Center

**PARTICIPANTS: 66**

**SUBTHEMES**

- **DYNAMIC AND NUCLEAR POWER SYSTEMS**
- **CONVENTIONAL POWER SYSTEMS**
- **THERMAL MANAGEMENT**

**DYNAMIC AND NUCLEAR POWER SYSTEMS**

	<b><u>VOTES</u> *</b>
<b>1. GAS COLLECTION AND RETENTION IN LIQ COOLANTS</b>	<b>372</b>
<b>2. FREEZE/THAW IN LIQ METAL SYSTEMS</b>	<b>317</b>
<b>3. GAS BUBBLE NUCLEATION/GROWTH IN LIQ METALS</b>	<b>238</b>
<b>4. TWO COMPONENT (SOLID/LIQUID) PUMPING/SEPARATION</b>	<b>221</b>
<b>5. TWO PHASE LIQ/GAS SEPARATION IN COOLANTS</b>	<b>197</b>
<b>6. LIGHT WEIGHT RADIATORS</b>	<b>173</b>
<b>7. TWO PHASE BOILING</b>	<b>171</b>
<b>8. PLASMA INTERACTION</b>	<b>158</b>
<b>9. ADVANCED POWER CONVERSION SYSTEMS</b>	<b>147</b>
<b>10. ENVIRONMENTAL EFFECTS</b>	<b>133</b>

• Technology issues were ranked from 1 to 10, with the most important receiving 10 votes, the next 9 votes, etc.

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Power Systems & Thermal Management Critical Technology Requirements***

**Roy McIntosh**  
NASA Goddard Space Flight Center

**CONVENTIONAL POWER SYSTEMS**

	<b><u>VOTES •</u></b>
1. ADVANCED ENERGY STORAGE	243
2. ADVANCED P.V. CELL TECHNOLOGY	200
3. PRIMARY & REGEN. FUEL CELLS	197
4. THERMAL ENERGY STORAGE	162
5. CONTAMINATION/UV & CHARGED PARTICLE P.V. EFFECTS	155
6. PRIMARY/SECONDARY BATTERIES	154
7. HIGH VOLTAGE/HIGH POWER SYSTEMS	146
8. HIGH PERFORMANCE ARRYS	142
9. HIGH DENSITY POWER SYSTEMS	141
10. HIGH POWER ARRAYS	138

• Technology issues were ranked from 1 to 10, with the most important receiving 10 votes, the next 9 votes, etc.

**THERMAL MANAGEMENT**

	<b><u>VOTES •</u></b>
1. TWO-PHASE HEAT TRANSFER	328
2. HEAT PIPES (LIQUID METAL CYRO)	250
3. CAPILLARY LOOPS	225
4. TWO PHASE FLOW & STABILITY	219
5. VOID BEHAVIOR FLIGHT TEST	201
6. HEAT PUMPS	185
7. TWO-PHASE AMMONIA TEST BED	182
8. THERMAL STORAGE	152
9. CYROGENIC TEST BED	139
10. ADVANCED RADIATORS	136

• Technology issues were ranked from 1 to 10, with the most important receiving 10 votes, the next 9 votes, etc.

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

3.3 Thermal Management

*Power Systems & Thermal Management Critical Technology Requirements*

Roy McIntosh  
NASA Goddard Space Flight Center

**CRITICAL TECHNOLOGIES**

**DYNAMIC AND NUCLEAR POWER SYSTEMS**

1. TWO COMPONENT FLOW AND PHASE CHANGE
  - He GAS NUCLEATION, SEPARATION AND COLLECTION
  - FREEZE/THAW (SYSTEMS)
  - KINETICS OF VOID FORMATION AND DISTRIBUTION BEHAVIOR
2. ADVANCED CONVERSION
  - HIGH EFFICIENCY PASSIVE CONVERSION (AMTEC, HYTEC)
  - DYNAMIC CONVERSION VALIDATION (STIRLING, BRAYTON)

**CRITICAL TECHNOLOGIES**

**CONVENTIONAL POWER SYSTEMS**

1. MICRO GRAVITY EFFECTS ON ADVANCED ELECTROCHEMICAL CONVERSION/STORAGE
  - REGENERATIVE FUEL CELLS
  - CELLS/BATTERIES
2. ADVANCED PHOTOVOLTAIC TECHNOLOGY
  - ENVIRONMENTAL EFFECTS (CELLS/CELL ASSEMBLIES)
    - SPACECRAFT INDUCED ENVIRONMENT
    - NATURAL ENVIRONMENT

Theme 3 of 8

**POWER SYSTEMS & THERMAL MANAGEMENT**

Theme 3 of 8

**3.3 Thermal Management**

***Power Systems & Thermal Management Critical Technology Requirements***

**Roy McIntosh**  
NASA Goddard Space Flight Center

**CRITICAL TECHNOLOGIES**  
**THERMAL MANAGEMENT**

- 1. TWO-PHASE FLOW STUDIES (TEST BED)**
  - **FUNDAMENTAL THERMAL HYDRAULICS**
    - HEAT TRANSFER
    - INSTABILITIES
    - PRESSURE DROPS
  - **SYSTEM AND COMPONENT RELATED STUDIES**
    - CAPILLARY PUMPED LOOPS
    - HEAT PUMP ISSUES
    - FLOW MANAGEMENT
- 2. ADVANCED HEAT PIPES**
  - CRYOGENIC HEAT PIPES
  - LIQUID METAL HEAT PIPES
  - INTERMEDIATE TEMPERATURE HEAT PIPES

**INTERACTIONS WITH OTHER THEMES**

<b><u>THEME</u></b>	<b><u>CONCERN</u></b>
<b>SPACE STRUCTURES</b>	<ul style="list-style-type: none"><li>• SOLAR ARRAY DEPLOYMENT</li><li>VIBRATION CONTROL</li></ul>
<b>SPACE ENVIRONMENTAL EFFECTS</b>	<ul style="list-style-type: none"><li>• ATOMIC OXYGEN DEGRADATION OF HIGH TEMP/HIGH E SURFACES</li><li>• ENVIRONMENTAL EFFECTS ON POWER SYSTEM COMPONENTS</li><li>• EFFECTS DATA BASE</li></ul>
<b>AUTOMATION AND ROBOTICS</b>	<ul style="list-style-type: none"><li>• ON ORBIT MAINTENANCE/REPAIR</li><li>• ARTIFICIAL INTELLIGENCE FOR POWER THERMAL SYSTEM CONTROL</li></ul>
<b>IN SPACE SYSTEMS</b>	<ul style="list-style-type: none"><li>• JOINING/WELDING</li></ul>

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

Background and Objectives

*Theme Organization and Purpose*

Lynn M. Anderson  
NASA Lewis Research Center

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## ORGANIZATION

**THEME LEADER: LYNN M. ANDERSON, LeRC**

**COMMITTEE:** EARL E. VANLANDINGHAM, OAST/RP  
WALTER F. BROOKS, ARC  
WILBERT ELLIS, JSC  
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KARL A. FAYMON, LeRC  
JOHN M. KRAMER, MSFC  
PLUS SUB-THEME SPEAKERS

**SUB-THEMES:** 1. ON-ORBT FLUID MANAGEMENT  
2. PROPULSION  
3. FLUID PHYSICS

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## THEME SESSION OBJECTIVES

**PURPOSE**

- Identify and prioritize in-space technologies for fluid management and propulsions systems by considering subtheme details which
  - are critical for future U.S. space programs.
  - require development and in-space validation.
- Generate comments and suggestions from aerospace community on OAST IN-STEP plans.

**PRODUCT**

- Priority listing of critical space technology needs and associated space flight experiments, recommended by aerospace community.

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.1 On-Orbit Fluid Management

#### *Fluid Management Technology*

John C. Aydelott  
NASA Lewis Research Center

### CRYOGENIC FLUID MANAGEMENT TECHNOLOGY ROADMAP

- EXAMINE FUTURE MISSIONS TO ESTABLISH NEEDS
  - EARTH-TO-ORBIT TRANSPORT OF CRYOGENS
  - IN-SPACE STORAGE AND SUPPLY (DEPOT)
  - FUELING OF SPACE-BASED TRANSFER VEHICLES
  - EXPERIMENT AND SATELLITE COOLANT RESUPPLY
  - HANDLING OF REACTANTS, COOLANTS, AND PROPELLANTS ON SPACE DEFENSE INITIATIVE SPACECRAFT
- CATEGORIZE TECHNOLOGY AND IDENTIFY IN-SPACE EXPERIMENTATION REQUIREMENTS
  - LIQUID STORAGE (THERMAL AND PRESSURE CONTROL)
  - LIQUID SUPPLY (PRESSURIZE, ACQUIRE, AND SUBCOOL)
  - LIQUID TRANSFER
  - FLUID HANDLING
  - INSTRUMENTATION
  - STRUCTURES AND MATERIALS

### CRYOGENIC FLUID MANAGEMENT TECHNOLOGY REQUIREMENTS

#### LIQUID STORAGE - THERMAL CONTROL SYSTEM PERFORMANCE

- EFFECT OF LAUNCH ENVIRONMENT ON THICK MULTILAYER INSULATION
- *LONG TERM SPACE ENVIRONMENT EFFECTS ON INSULATION (DEBRIS, MICROMETEROIDS AND ATOMIC OXYGEN)*
- COMBINED EARTH/ORBIT INSULATION
- COOLING ENHANCEMENT PROVIDED BY PARA-TO-ORTHO CONVERSION
- MULTIPLE/COUPLED VAPOR COOLED SHIELDS

#### LIQUID STORAGE - PRESSURE CONTROL

- *THERMODYNAMIC VENT SYSTEM PERFORMANCE*
- *FLUID MIXING FOR STRATIFICATION CONTROL*
- REFRIGERATION/LIQUEFACTION SYSTEM DEMONSTRATION (INCLUDING CONDENSATE COLLECTION)

Italicized items must be addressed via flight experiments, however, some information can be obtained via ground based experiments

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.1 On-Orbit Fluid Management

***Fluid Management Technology***

John C. Aydelott  
NASA Lewis Research Center

**CRYOGENIC FLUID MANAGEMENT TECHNOLOGY REQUIREMENTS**

**LIQUID SUPPLY - PRESSURIZATION SYSTEM PERFORMANCE**

- *AUTOGENOUS (INCLUDING PARA/ORTHO COMPOSITION)*
- *HELIUM*
- MECHANICAL (PUMPS/COMPRESSORS)

**LIQUID SUPPLY - FLUID ACQUISITION/SUBCOOLING**

- *FINE MESH SCREEN LIQUID ACQUISITION DEVICE (LAD) EXPULSION EFFICIENCY*
- *REORIENTATION & OUTFLOW VIA IMPULSIVE ACCELERATION*
- *REORIENTATION & OUTFLOW UNDER CONSTANT LOW-GRAVITY CONDITIONS*
- *THERMAL EFFECTS ON LAD PERFORMANCE*
- THERMAL SUBCOOLING OF LIQUID OUTFLOW

**LIQUID TRANSFER**

- *TRANSFER LINE CHILLDOWN*
- *TANK CHILLDOWN WITH SPRAY*
- *NO-VENT FILL*
- *LIQUID ACQUISITION DEVICE (LAD) FILL*
- *LOW-GRAVITY VENTED FILL*

**FLUID HANDLING**

- *LIQUID DYNAMICS/SLOSH CONTROL*
- *FLUID DUMPING/TANK VENTING AND INERTING*
- *FARTH-TO-ORBIT TRANSPORT AS SUBCOOLED LIQUID OR LIQUID/SOLID MIXTURE (SLUSH)*

**ADVANCED INSTRUMENTATION**

- *QUANTITY GAGING*
- *MASS FLOW/QUALITY METERING*
- *LEAK DETECTION*
- *LIQUID/VAPOR SENSORS*

**TANK STRUCTURES AND MATERIALS**

- *COMPOSITE (LIGHT WEIGHT) VACUUM JACKET*
- *LOW THERMAL CONDUCTIVITY COMPONENTS*
- *LOW PRESSURE TANKAGE*
- *CONTAMINATION/DEGRADATION OF LIQUID ACQUISITION DEVICE*

*Italicized items must be addressed via flight experiments, however, some information can be obtained via ground based experiments*

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.1 On-Orbit Fluid Management

#### *Cryogenic Fluid Management Technology*

John R. Schuster  
General Dynamics, Space Systems Division

#### BACKGROUND

##### TRANSPORTATION MISSIONS

##### POSSIBLE DATES

- |  |           |
|--|-----------|
| • Interim Space Transfer Vehicle (STV) | 1998      |
| • Space-Based STV                      | 2001      |
| • Orbital Propellant Depot             | 2001      |
| • Lunar Base                           | 2005      |
| • Piloted Mars Expedition              | 2003-2008 |

##### SYSTEM DEVELOPER ROLES

##### DEVELOPMENT CHALLENGES

- |                                     |                                   |
|-------------------------------------|-----------------------------------|
| • Design/Fabrication                | • Achieve Adequate Risk Reduction |
| • Engineering Data Base Development | • Contend with Constraints        |
| • Performance Modeling              | • Available Testing Environments  |
| • Environmental Validation          | • Schedule                        |
| • System Validation                 | • Budget                          |
|                                     | • Institutional Considerations    |

#### OBSERVATIONS

- **BOTTOM LINE IS RISK REDUCTION**
  - Testing and validation methods must be affordable
  - Test results must be timely to support development schedules
- **UNIVERSAL PROBLEM**
  - Mission planners awed by development challenges
    - Feasibility evaluations become prolonged
    - IOC dates slip
  - Missions too weakly supported to exert technology pull
    - Technology development is slowed
    - Technology development requires long-term commitment
    - In-space testing can be expensive
- **MISSION PLANNERS AND TECHNOLOGISTS NEED TO GET IN STEP**
  - Link technology development to program milestones
  - Begin technology development early
  - Achieve synergism
    - Programs will "pull" technology
    - Technology advances will "push" programs

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.1 On-Orbit Fluid Management

#### *Cryogenic Fluid Management Technology*

John R. Schuster

General Dynamics, Space Systems Division

### TECHNOLOGY NEEDS

#### MISSION CRITICALITY

Technology Category	MISSION CRITICALITY					
	Interim STV	Space-Based STV	Orbital Depot	Resupply Tanker	Lunar Base	Mars Expedition
• Liquid Storage						
- Thermal Control Systems						
• Degradation of Material		Enhance	Enhance		Enhance	Enable
• Effect of Launch Env. on Thick MLI	Enable	Enable	Enable	Enhance	Enable	Enable
• Combined Foam/MLI Sys.	Enhance			Enhance		
• Para/Ortho Conversion			Enhance		Enhance	Enhance
• Multiple/Coupled VCS			Enhance		Enhance	Enable
- Pressure Control Systems						
• TVS Performance	Enhance	Enhance	Enable	Enhance		Enable
• Fluid Mixing for Stratification Control	Enhance	Enhance	Enable	Enhance		Enable
• Refrigeration/Reliquefaction			Enhance		Enhance	Enable ?
• Liquid Supply						
- Pressurization System Perf.						
• Autogenous	Enhance	Enable	Enable	Enhance	Enable	Enable
• Helium	Enable					
• Mech. (Pumps/Comp.)			Enhance	Enhance	Enhance	Enhance
- Fluid Acquisition						
• Fine Mesh Screen LAD Performance		Enhance ?	Enable	Enable		Enable
• Fluid Settling & Outflow under Low G Conditions	Enhance	Enhance	Enhance	Enhance		Enhance
• Fluid Settling & Outflow under Impulsive Accel	Enhance	Enhance		Enhance		Enhance
• Impact of Heat Addition on LAD Performance		Enhance	Enhance ?	Enhance		Enhance
• Thermal Subcooling of Liquid Outflow			Enhance	Enhance	Enhance	Enhance
• Liquid Transfer						
- Transfer Line Chillover		Enable	Enable	Enhance	Enable	Enable
- Tank Chillover with Spray		Enable	Enhance			Enhance
- No-Vent Fill		Enable	Enable			Enhance
- LAD Fill		Enhance ?	Enhance			Enhance
- Low G Vented Fill		Enhance	Enhance			Enhance
- Pump Assist		Enhance	Enhance	Enhance	Enhance	Enhance
• Fluid Handling						
- Liquid Dynamics/Slush Control	Enhance	Enhance	Enhance	Enhance		Enhance
- Fluid Dumping & Tank Inerting		Enable	Enable	Enhance		Enhance
- Earth-to-Orbit Transport as Subcooled Liquid or Slush	Enhance	Enhance	Enhance	Enhance		Enhance
• Advanced Instrumentation						
• Quantity Gauging	Enhance	Enhance	Enable			Enhance
• Mass Flow/Quality metering			Enhance		Enhance	Enhance
• Leak Detection		Enhance	Enable		Enable	Enable
• Liquid/Vapor Sensors	Enhance	Enable	Enable	Enhance	Enable	Enable
• Tank Structures & Materials						
• Low Thermal Conductivity Components	Enhance	Enhance	Enhance	Enhance	Enhance	
• Low Pressure Tankage	Enhance	Enhance				Enhance
• Composite(Light Weight)						
• Vacuum Jackets	Enhance			Enhance		
• Contamination/Degradation of LAD		Enhance ?	Enhance			Enhance

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.1 On-Orbit Fluid Management

### *Cryogenic Fluid Management Technology*

John R. Schuster

General Dynamics, Space Systems Division

## IN-SPACE EXPERIMENTATION NEEDS

### TESTING OBJECTIVE

Technology Category	Engineering Data Base	Performance Modeling	Environmental Validation	System Validation yes	In-Space Testing Req'd yes
• Liquid Storage					
• Thermal Control Systems					
• Degradation of Material	yes		yes		yes
• Effect of Launch Env. on Thick MLI	yes		yes		
• Combined Foam/MLI Sys.	yes	yes	yes		
• Para/Ortho Conversion	yes	yes			
• Multiple/Coupled VCS	yes	yes			
• Pressure Control Systems					
• TVS Performance	yes	yes	yes		yes
• Fluid Mixing for Stratification Control	yes	yes	yes		yes
• Refrigeration/Reliquefaction	yes	yes			
• Liquid Supply				yes	yes
• Pressurization System Perf.					
• Autogenous	yes	yes	yes		yes
• Helium	yes	yes	yes		yes
• Mech. (Pumps/Comp.)	yes	yes			
• Fluid Acquisition					
• Fine Mesh Screen LAD Performance	yes	yes	yes		yes
• Fluid Settling & Outflow under Low G Conditions	yes	yes	yes		yes
• Fluid Settling & Outflow under Impulsive Accel	yes	yes	yes		yes
• Impact of Heat Addition on LAD Performance	yes	yes			
• Thermal Subcooling of Liquid Outflow	yes	yes			
• Liquid Transfer				yes	yes
• Transfer Line Chilldown	yes	yes	yes		yes
• Tank Chilldown with Spray	yes	yes	yes		yes
• No-Vent Fill	yes	yes	yes		yes
• LAD Fill	yes	yes	yes		yes
• Low G Vented Fill	yes	yes	yes		yes
• Pump-Assist	yes	yes			
• Fluid Handling				yes	yes
• Liquid Dynamics/Slosh Control	yes	yes	yes		yes
• Fluid Dumping & Tank Inerting	yes	yes	yes		yes
• Earth to Orbit Transport as Subcooled Liquid or Slush	yes	yes			
• Advanced Instrumentation				yes	yes
• Quantity Gauging	yes	yes	yes		yes
• Mass Flow/Quality metering	yes	yes			
• Leak Detection	yes	yes			
• Liquid/Vapor Sensors	yes	yes			
• Tank Structures & Materials					
• Low Thermal Conductivity Components	yes	yes	yes		
• Low Pressure Tankage	yes		yes		
• Composite(Light Weight) Vacuum Jackets	yes	yes			
• Contamination/Degradation of LAD	yes				

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

***Low Thrust Propulsion Space Experiments***

**J.R. Stone**

NASA Hqs, Office of Aerospace Science & Technology — Propulsion, Power & Energy Division

**INTRODUCTION/BACKGROUND**

- **THE NASA LOW THRUST PROPULSION PROGRAM PROVIDES THE TECHNOLOGY FOR ADVANCED ON-BOARD PROPULSION FOR FUTURE SPACE SYSTEMS:**
  - SPACECRAFT
  - PLATFORMS
  - TRANSPORTATION VEHICLES
- **LOW THRUST PROPULSION TECHNOLOGIES**
  - **CHEMICAL: HYDROGEN/OXYGEN**  
**STORABLES**
  - **ELECTRIC: AUXILIARY**  
**PRIMARY**

**MISSION APPLICATIONS**

- **ORBIT TRANSFER**
  - SATELLITE PLACEMENT/RETURN
  - LOGISTICS
- **STATIONKEEPING**
  - DRAG & SOLAR PRESSURE
  - EPHEMERIS CONTROL

**IMPACT OF LOW THRUST PROPULSION TECHNOLOGY ADVANCEMENT**

- **MASS SAVINGS FOR**
  - SPACECRAFT
  - PLATFORMS
  - VEHICLES

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

***Low Thrust Propulsion Space Experiments***

J.R. Stone

NASA Hqs, Office of Aerospace Science & Technology — Propulsion, Power & Energy Division

**TECHNOLOGY NEEDS/OPPORTUNITIES**

- 1-kw CLASS, STORABLE PROPELLANT ARCJET FOR APPLICATIONS SUCH AS COMMUNICATIONS SATELLITE STATIONKEEPING
  - LONG LIFE
  - HIGH DEGREE OF COMMONALITY W. S-O-A SYSTEMS
  - MINIMAL IMPACT ON OTHER SPACECRAFT SYSTEMS/SUBSYSTEMS
- MULTIPROPELLANT RESISTOJETS FOR SPACE STATION FREEDOM AND TENDED PLATFORMS
  - LONG LIFE
  - MINIMIZE LOGISTICS REQUIREMENTS
  - MINIMAL IMPACT ON OTHER SPACECRAFT SYSTEMS/SUBSYSTEMS
- INTEGRATED AUXILIARY PROPULSION FOR LAUNCH & TRANSFER VEHICLES
  - SAVE MASS BY USING RESIDUAL PRIMARY PROPELLANTS
  - SIMPLIFY LOGISTICS (MINIMIZE NUMBER OF FLUIDS HANDLED)
- HIGH POWER ELECTRIC PROPULSION FOR LUNAR/PLANETARY EXPLORATION AND CARGO VEHICLES
  - VERY LONG LIFE, HIGH PERFORMANCE ION & MPD SYSTEMS
  - GROUND FACILITY (POWER/PUMPING/VACUUM) CAPABILITY TO PROVIDE ADEQUATE SPACE SIMULATION NOT ESTABLISHED

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- ADDRESS CRITICAL CRITICAL CONCERNS OF POTENTIAL USERS OF ADVANCED PROPULSION TECHNOLOGY
  - PLUME CONTAMINATION AND PERFORMANCE IMPACTS (BOTH CHEMICAL AND ELECTRIC PROPULSION)
  - ELECTROMAGNETIC INTERFERENCE (CONDUCTED AND RADIATED)
  - SPACECRAFT CHARGING
- VALIDATE PERFORMANCE AND LIFE TEST RESULTS FROM GROUND SIMULATION FACILITIES
- MINIMIZE RISK FOR POTENTIAL USERS BY PROVIDING INITIAL DEMONSTRATION OF ADVANCED TECHNOLOGY

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

***Low Thrust Propulsion Space Experiments***

**J.R. Stone**

NASA Hqs, Office of Aerospace Science & Technology — Propulsion, Power & Energy Division

**SUMMARY/RECOMMENDATIONS**

- **HIGHEST PRIORITY IS TO CONTINUE TO DEVELOP THE ARCJET FLIGHT TEST OPPORTUNITY ON A COMMERCIAL COMMUNICATIONS SATELLITE**
- **VERIFY IN SPACE THE VALIDITY OF COMPUTATIONAL PREDICTIONS AND GROUND-TEST ASSESSMENTS OF PLUME IMPACTS**
- **VALIDATE THE ADEQUACY OF GROUND TEST FACILITIES FOR HIGH-POWER ELECTRIC PROPULSION TESTS**
- **ASSESS THE MERIT OF DEVELOPING A TESTBED CAPABILITY FOR PROPULSION, PROBABLY AS A COMBINED FACILITY APPLICABLE TO OTHER ADVANCED TECHNOLOGIES, SUCH AS POWER**

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.2 Propulsion

#### *Key Propulsion Technologies for In-Space Experiments*

James H. Kelley  
Jet Propulsion Laboratory

## INTRODUCTION / BACKGROUND

- TWO KEY PROPULSION TECHNOLOGIES NEED FLIGHT DATA  
SOLAR ELECTRIC PROPULSION (SEP)
  - Xe ION IN PARTICULARROCKET EXHAUST PLUME TECHNOLOGY
- BOTH TECHNOLOGIES WILL DRAMATICALLY AFFECT DESIGNS  
AND PLANNING FOR FUTURE SPACECRAFT AND MISSIONS
- SEP WOULD BE WIDELY USED WERE IT NOT FOR:  
DEVELOPMENT COST / RISK  
UNKNOWNNS REGARDING IN SPACE BEHAVIOR  
LACK OF FLIGHT EXPERIENCE
- ROCKET EXHAUST PLUMES (ESPECIALLY BIPROPELLANT ACS  
THRUSTERS) CAN DEGRADE S/C PERFORMANCE THROUGH:  
FORCES AND MOMENTS  
HEATING  
CONTAMINATION

## TECHNOLOGY NEEDS

- RELIABLE, VALIDATED, PREDICTIVE MODELS OF:  
CONTAMINANT GENERATION  
NOZZLE AND PLUME FLOW FIELDS  
PLUME / SURFACE INTERACTIONS  
CONTAMINANT PROPERTIES
- PRESENT MODELS ARE DEFICIENT  
KNOWN TO CONTAIN ERRONEOUS ASSUMPTIONS  
WHERE BASIC PHYSICAL UNDERSTANDING IS MISSING

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

*Key Propulsion Technologies for In-Space Experiments*

James H. Kelley  
Jet Propulsion Laboratory

**TECHNOLOGY NEEDS**

○ **DEVELOPMENT AND INTEGRATION OF COMPLETE SEPS SYSTEM**

**Xe ION ENGINE**

**POWER PROCESSOR**

**CONTROLLER**

**LIGHT WEIGHT SOLAR ARRAY**

○ **DEMONSTRATION OF PERFORMANCE AND LIFE**

**S/C CHARGING ISSUES**

**PLASMA EFFECTS ON SOLAR ARRAY**

**ENGINE LIFE AND PERFORMANCE**

○ **DEVELOPMENT OF PREDICTIVE PLUME CAPABILITY REQUIRES**

**IMPROVED UNDERSTANDING OF COMBUSTION IN  
PULSED ROCKET ENGINES**

**DEVELOPMENT OF NOZZLE FLOW FIELD CODES FOR  
FULLY TRANSIENT, VISCOUS, REACTING FLOWS**

**DEVELOPMENT AND VALIDATION OF CODES TO  
PREDICT RAREFIED PLUME FLOW FIELDS**

○ **COLLECTION OF QUALITY EXPERIMENTAL DATA IS A  
FORMIDABLE TASK**

**IMPROVED DIAGNOSTICS NEEDED**

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

*Key Propulsion Technologies for In-Space Experiments*

James H. Kelley  
Jet Propulsion Laboratory

**IN-SPACE EXPERIMENTATION NEEDS / VOIDS**

- SEP-INDUCED PLASMA / SPACECRAFT INTERACTIONS CAN ONLY BE EVALUATED IN SPACE

**SPACECRAFT CHARGING EFFECTS**

**PLASMA-INDUCED LEAKAGE CURRENTS ON SOLAR ARRAY**

- SERT FLIGHT TESTS OF MERCURY ION ENGINES IN THE 1960s REVEALED THAT ENGINE LIFE CAN BE LIMITED BY MECHANISMS UNIQUE TO SPACE (i.e., ZERO G)

**IN-SPACE DEMONSTRATION REQUIRED TO PROVIDE ACCEPTABLE RISK FOR USERS OF SEP!**

- GROUND-BASED TESTS CAN NOT SIMULATE THE EXPANSION OF A ROCKET EXHAUST PLUME INTO A SPACE ENVIRONMENT

**PLUME DENSITIES AS LOW AS 10 MOLECULES/CC ARE OF INTEREST**

**DENSITY OF BACKGROUND IN THE BEST SPACE SIMULATORS IS MORE THAN 10 ORDERS OF MAGNITUDE TOO HIGH**

- CONTAMINANT (i.e., DROPLET) GENERATION AND TRANSPORT IS ALTERED BY GRAVITY IN GROUND TESTS
- DATA COLLECTED IN SPACE TO DATE MONITORS CONTAMINATION BUT DOES NOT:

**UNIQUELY IDENTIFY SOURCE**

**ADEQUATELY CHARACTERIZE CONTAMINANT PROPERTIES**

**ALLOW DETERMINATION OF WHAT PROBLEMS EXIST IN PREDICTIVE METHODS, e.g.;**

**INCORRECT MODEL OF CONTAMINANT GENERATION?**

**INCORRECT MODEL OF RAREFIED FLOW FIELD?**

**INADEQUATE MODEL OF SURFACE INTERACTIONS?**

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

***In-Space Technology Experiments in Propulsion: The Role of Universities***

**Charles L. Merkle**

Distinguished Alumni Professor, Pennsylvania State University, Mechanical Engineering

**INTRODUCTION / BACKGROUND**

- UNIVERSITY PARTICIPATION IN SPACE EXPERIMENTATION REQUIRES INNOVATION
- TRADITIONAL UNIVERSITY RESEARCH ROLES NOT EFFECTIVE IN SPACE EXPERIMENTATION
- LEAD TIMES FOR SPACE EXPERIMENTS CAN EXCEED STUDENT DEGREE PROGRAMS
- COMPLEXITY OF SPACE EXPERIMENTATION REQUIRES GROUP PARTICIPATION
- IMPORTANT TO GET FACULTY ATTENTION/COMMITMENT TO INTERDISCIPLINARY RESEARCH

**TECHNOLOGY ISSUES**

- PROPULSION PERTAINS TO ALL SPACE MISSIONS
- DIVERSE MISSION REQUIREMENTS DEFINE NEED FOR BROAD RANGE OF PROPULSION SYSTEMS
  - Sizes      - Concepts      - Capabilities
- BOTH PROPULSION AND SPACE EXPERIMENTATION ARE STRONGLY MULTIDISCIPLINARY
- EMPHASIS ON SAFETY/PACKAGING/INTEGRATION REQUIRES DIVERSE EXPERTISE BEYOND SPECIFIC EXPERIMENT
- IN-SPACE EXPERIMENTATION REQUIRES LONG LEAD TIMES
  - May Exceed Degree Lengths

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.2 Propulsion

***In-Space Technology Experiments in Propulsion: The Role of Universities***

**Charles L. Merkle**

Distinguished Alumni Professor, Pennsylvania State University, Mechanical Engineering

**ATTRIBUTES OF UNIVERSITIES FOR IN-STEP**

- PRIMARY SOURCE OF NEW TALENT TO NASA/INDUSTRY
- POTENTIAL UNIVERSITY CONTRIBUTIONS INCLUDE:
  - Get Graduates Aware/Interested in Space Experimentation
  - Impact Curricula to Provide Graduates With Proper Background
  - Bring Expertise of Faculty to Bear on Fundamental Problems
  - Provide Direct Input in Terms of Research Findings
- UNIVERSITY RESEARCH HAS HISTORICALLY FOCUSED ON:
  - Independent Researchers
  - Simple Experiments
  - Providing In-Depth Understanding From Detailed Measurements
- IN-STEP REQUIRES:
  - Group Participation
  - Single Shot Experiments
  - In-Depth Understanding from Limited Information

**SUMMARY / RECOMMENDATIONS**

- UNIVERSITIES MUST FUNCTION AS SUB-ELEMENTS OF NASA/INDUSTRY GROUPS
- TRADITIONAL ROLE OF FACULTY AS INDEPENDENT INVESTIGATORS MUST BE MODIFIED
- ATTEMPTS SHOULD BE MADE TO KEEP FACULTY INVOLVED IN SIMPLE, FUNDAMENTAL EXPERIMENTS
- IMPORTANT TO INVOLVE UNIVERSITIES TO IMPACT GRADUATES' AWARENESS, INTEREST, AND EXPERTISE
- IN-SPACE ROLE OF STUDENTS/FACULTY IS EXPECTED DOWNSTREAM
- FACULTY/UNIVERSITIES NEED ENCOURAGEMENT TO PARTICIPATE IN INTERDISCIPLINARY PROGRAMS

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

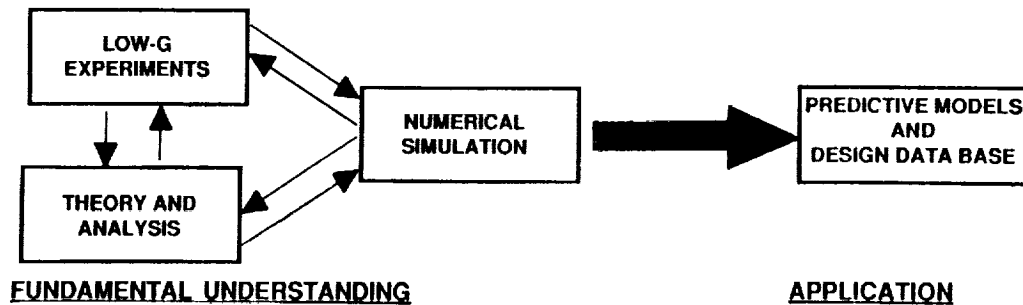
#### *Fluid Physics*

Jack A. Salzman  
NASA Lewis Research Center

#### OBJECTIVE

ENHANCE THE FUNDAMENTAL UNDERSTANDING OF FLUID BEHAVIOR AND DYNAMICS IN A REDUCED GRAVITY ENVIRONMENT TO ENABLE THE DEVELOPMENT OF ADVANCED SPACE SYSTEMS.

#### PROCESS



#### APPROACH

SYSTEMATIC AND STRUCTURED PROGRAM OF CONDUCTING LOW-GRAVITY FLUIDS EXPERIMENTS GUIDED BY THEORETICAL ANALYSES AND NUMERICAL SIMULATION TO PROGRESSIVELY BUILD UNDERSTANDING AND DATA BASES

#### BACKGROUND

- EXTENSIVE LOW-GRAVITY FLUID RESEARCH PROGRAM DURING 1960'S AND EARLY 1970'S
- RANGE OF CRITICAL FLUID MANAGEMENT ISSUES/PROBLEMS IDENTIFIED AND ADDRESSED
  - FOCUSED MISSION/SYSTEM DRIVEN RESEARCH
  - DEPTH OF BASIC UNDERSTANDING LIMITED TO SPECIFIC GOALS SET FOR EACH MISSION
  - CRITICAL ENABLING FLUID MANAGEMENT FUNCTIONS IN SPACE ACCOMPLISHED
- LOW-GRAVITY FLUIDS RESEARCH IN LATE 1970'S AND EARLY 1980'S AT MAINTENANCE LEVEL
  - CRYOGENIC FLUIDS PROGRAMS
  - PHYSICS AND CHEMISTRY EXPERIMENTS PROGRAM (PACE)
- RENEWED INTEREST WITH NEW MISSION DRIVERS
  - MANY OF THE SAME OLD PROBLEMS
  - NEW SPECIFIC PROBLEMS BUT SAME BASIC FLUID PROCESSES

#### STATUS

PREDICTIVE MODELS FOR LOW-GRAVITY FLUID BEHAVIOR AND PROCESSES ARE INADEQUATE, INACCURATE, AND POTENTIALLY MISLEADING

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

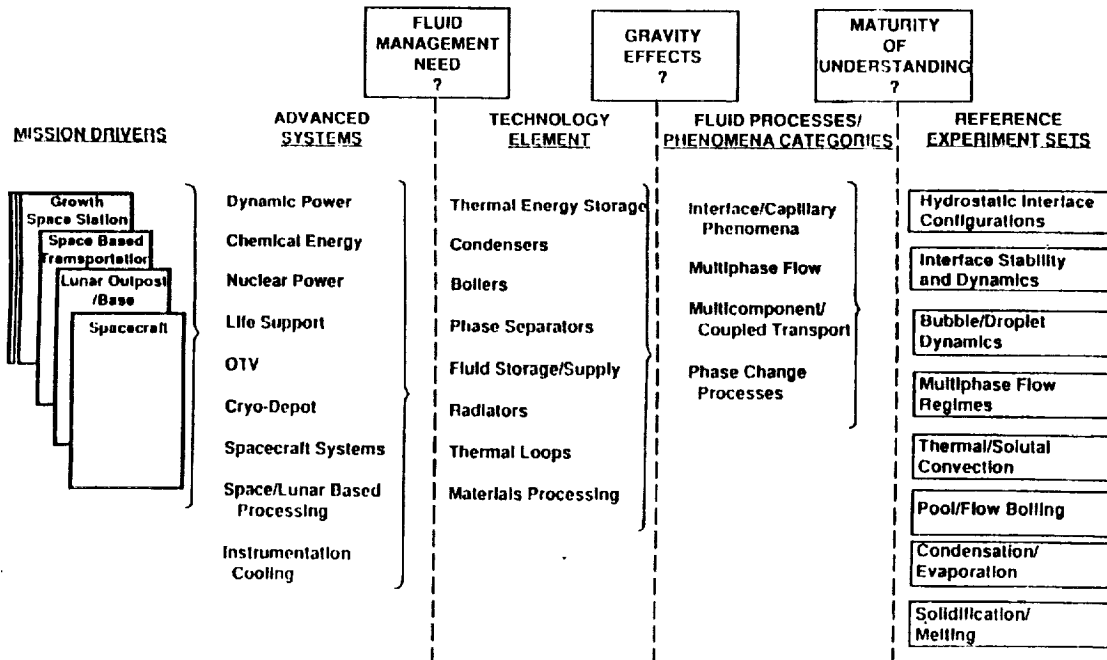
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### 4.3 Fluid Physics

#### Fluid Physics

Jack A. Salzman  
NASA Lewis Research Center

### GENERAL PLANNING MODEL



#### REFERENCE EXPERIMENT SET OBJECTIVES

ESTABLISH AND VERIFY ANALYTICAL/NUMERICAL MODELS TO PREDICT:

#### HYDROSTATIC INTERFACE CONFIGURATIONS

THE BULK LIQUID LOCATION AND THE CONFIGURATION OF THE EQUILIBRIUM LIQUID-GAS INTERFACE AS A FUNCTION OF FLUID PROPERTIES, VESSEL GEOMETRY AND SIZE, GRAVITY LEVEL, AND SYSTEM INITIAL CONDITIONS

#### INTERFACE STABILITY AND DYNAMICS

THE RESPONSE OF A REDUCED-GRAVITY LIQUID-VAPOR INTERFACE TO MECHANICAL AND THERMAL DISTURBANCES AND ITS EFFECTS ON BULK LIQUID MOTION

#### BUBBLE/DROPLET DYNAMICS

THE BUOYANCY AND/OR THERMALLY DRIVEN MOTION OF SINGLE BUBBLE/ DROPLET UNDER REDUCED GRAVITY CONDITIONS AND THE INTERACTIONS BETWEEN MULTIPLE BUBBLES/DROPLETS INCLUDING COALESCENCE/BREAKUP

#### MULTIPHASE FLOW REGIMES

THE FLOW REGIME PATTERNS & CHARACTERISTICS GENERATED BY THE FORCED ADIABATIC FLOW OF LIQUID-VAPOR OR IMMISCIBLE LIQUID MIXTURES THROUGH CONDUITS AND FITTINGS AS A FUNCTION OF FLUID PROPERTIES, FLOW RATES, CONDUIT/FITTING GEOMETRY AND SIZE, AND GRAVITY LEVEL

#### THERMAL/SOLUTAL CONVECTION

THE HEAT AND MASS TRANSFER GENERATED BY BUOYANCY DRIVEN FLOWS RESULTING FROM THERMAL AND/OR CONCENTRATION GRADIENTS UNDER REDUCED GRAVITY CONDITIONS.

#### POOL/FLOW BOILING

THE ONSET OF NUCLEATE BOILING AND SUBSEQUENT BUBBLE DYNAMICS AS A FUNCTION OF SYSTEM SATURATION SUBCOOLING, HEAT FLUX, FLUID PROPERTIES, HEATER GEOMETRY, AND GRAVITY LEVEL FOR BOTH STAGNANT AND LIQUID FLOW CONDITIONS.

#### CONDENSATION/EVAPORATION

THE CONDITIONS FOR CONDENSATION/EVAPORATION OF LIQUID AT LIQUID-VAPOR INTERFACES AND ITS EFFECTS ON INTERFACE STABILITY/DYNAMICS UNDER LOW-GRAVITY CONDITIONS FOR BOTH STAGNANT AND VAPOR FLOW CONDITIONS

#### SOLIDIFICATION/MELTING

THE DYNAMIC BEHAVIOR OF THE SOLID-FLUID FRONT DURING SOLIDIFICATION AND/OR MELTING UNDER LOW-GRAVITY CONDITIONS WITH SPECIAL EMPHASIS ON VOID FORMATION AND DYNAMICS DUE TO VOLUME CHANGES.

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

#### *Fluid Physics*

Jack A. Salzman  
NASA Lewis Research Center

#### IN-SPACE EXPERIMENT DESIGN OPTIONS

- ALL EXPERIMENT REFERENCE SET OBJECTIVES CAN BE ACHIEVED THROUGH TWO APPROACH OPTIONS
  - SEVERAL ( $\geq 7$ ) SPECIALIZED SETS OF EXPERIMENT HARDWARE WITH LIMITED COMPLEXITY/CAPABILITIES
  - TWO OR THREE SETS OF FACILITY CLASS HARDWARE
- CHOICE OF APPROACH DICTATED BY
  - MANIFEST OPPORTUNITIES
  - BASIC IN-STEP PHILOSOPHIES ON PROGRAM STRUCTURE (E.G., INDIVIDUAL EXPERIMENTER PROVIDED HARDWARE VS NASA FURNISHED HARDWARE FOR EXPERIMENT TEAMS)
  - EXISTENCE OF CRITICAL TIMELINE FOR DATA ACQUISITION

#### ONE POSSIBLE SPACE FACILITY APPROACH

- INITIALLY IMPLEMENT ADIABATIC MULTIPHASE FLOW CLOSED-LOOP SYSTEM
  - SINGLE LIQUID-GAS PAIR
  - STRAIGHT CONDUIT TEST SECTION
  - LIMITED DIAGNOSTICS
- FIRST ADD CAPABILITIES FOR
  - ISOLATED TEST SECTION WITH HEATERS FOR POOL BOILING EXPERIMENT
  - MULTIPLE LIQUID-GAS PAIRS
  - INCREASED DIAGNOSTICS
- NEXT ADD CAPABILITIES FOR
  - FLOW BOILING EXPERIMENTS
  - FLOW THROUGH FITTINGS
  - INCREASED DIAGNOSTICS
- NEXT ADD CAPABILITIES FOR
  - FLOW CONDENSATION EXPERIMENTS
  - MULTIPLE BUBBLE/DROP COALESCENCE & MIGRATION EXPERIMENTS

Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

#### *Low-G Interface Configurations, Stability and Dynamics*

Franklin T. Dodge  
Southwest Research Institute

#### **BACKGROUND AND GENERAL OBSERVATIONS**

Interface configurations, stability, and dynamics have a prominent effect on spacecraft design and operations.

1. Progress in predictive methods (CFD codes) is hampered by lack of understanding of free-surface physics in low gravity (e.g., contact line motion).
2. Interface motions in many cases interact with other systems.
3. For cryogenics, interface motions can affect heat transfer, vaporization, and other thermal effects.

This discussion will focus on:

- Identifying important liquid processes
- technology needed to solve the problems
- required in-space experimentation
- problems caused by lack of predictive understanding

Discussion will use examples of satellites and OTV.

#### **EXAMPLE: Orbiting Satellite**

**Fluid Process:** Interface Configuration

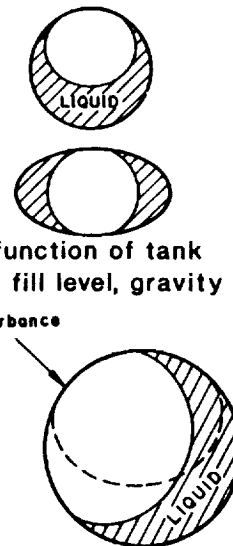
**Problem:** Since interface locations are unknown, "propellant management devices" are used to insure gas-free liquid. This increases weight/complexity and decreases reliability.

**Technology Need:** Predict interface location as a function of tank geometry, fluid properties, tank surface properties, fill level, gravity vector, and history of satellite operations.

**Fluid Process:** Interface stability - what disturbance level (satellite motion) will cause an interface to re-locate

**Problem:** PMD's are used to circumvent the problem. Complexity and weight increase, and reliability decreases.

**Technology Need:** Accurate prediction of the required acceleration needed to de-stabilize an interface



Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.3 Fluid Physics

***Low-G Interface Configurations, Stability and Dynamics***

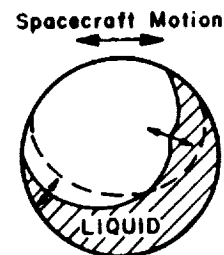
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***ORBITING SATELLITE (cont'd)***

***Fluid Process:*** Interface Dynamics

***Problem:*** Maneuvering sets the liquid in motion; this feeds back disturbances. The maneuver is degraded (Peacekeeper, space telescope, SDI systems, comm. satellites)

***Technology Need:*** Surface tension and contact line dynamics control the liquid motion. Physics of the motion is not understood. Motions may not be small. Need to predict motions as a function of tank shape, liquid properties, tank surface properties, fill level, and spacecraft motion. (Current CFD codes are of limited use because of poor surface physics.)

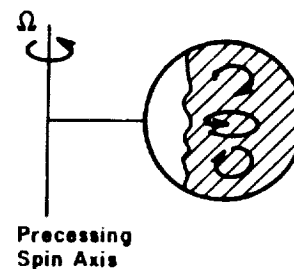


***EXAMPLE: Spin Stabilized Satellite***

***Fluid Process:*** Liquid configuration and motion in a tank spinning about an axis outside the tank, when surface tension is important.

***Problem:*** Liquid motions and viscous dissipation can not be predicted. Spacecraft design is thus very conservative or even abandoned in favor of non-spinners.

***Technology Need:*** Liquid motions do not resemble non-spinning motions (e.g., a free-surface is not necessary). No good theory exists. Ground-based tests are of limited value. Need to predict motions and energy dissipation and the influence of surface physics.



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## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

#### *Low-G Interface Configurations, Stability and Dynamics*

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#### **EXAMPLE: OTV**

**Fluid Process:** Interface configuration and stability

**Problems:**

- gas-free liquid transfer
- quantity-gaging - liquid location is unknown so elaborate, heavy, complex, and limited accuracy systems are used.

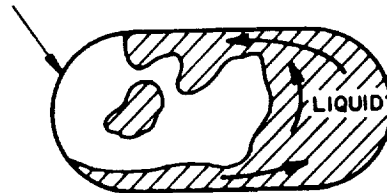
**Technology Need:** Accurate prediction of interface location so a simple, reliable, accurate gaging system can be used.

**Fluid Process:** Interface dynamics and bulk liquid motion.

**Problem:** Docking causes large impulsive accelerations. The liquid undergoes gross motions which degrade control and increase liquid transfer time.

**Technology Need:** Validate method (CFD code) to predict large free-surface motions in low-g and the duration of such motions

DOCKING IMPULSE



#### **IN-SPACE EXPERIMENTATION NEEDS**

##### **Interface configuration and stability**

High-quality reference set of data to verify and guide analytical/numerical models

##### **Interface slosh dynamics**

Highly instrumented reference data sets to guide and verify analytical/numerical models (wave shape, natural frequency, forces and moments, nonlinear effects, damping).

##### **Liquid dynamics in spinning tanks**

Acquire fundamental understanding to illuminate the physics and guide/validate models

##### **Large amplitude interface motions**

Reference data sets to verify numerical models

#### **PRIORITIZATION OF IN-SPACE EXPERIMENTATION**

##### **Phase 1**

- Interface slosh dynamics
- Liquid dynamics in a spinning tank

##### **Phase 2**

- Interface configuration
- Interface stability
- Large interface motions

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## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

#### *The Case for Two-Phase Gas-Liquid Flow Experiments In Space*

A.E. Dukler

University of Houston, Chemical Engineering Department

#### BACKGROUND

- TWO PHASE FLOW WILL EXIST IN MANY APPLICATIONS IN SPACE
  - RANKIN POWER CYCLE
  - EMERGENCY NUCLEAR COOLING SYSTEMS
  - SPACE STATION THERMAL BUS
  - TRANSFER LINES FOR RESUPPLY OF CRYOGEN TANKS
  - PROJECTED CHEMICAL PROCESSING OPERATIONS
- GRAVITY LEVEL HAS A PROFOUND EFFECT ON THESE FLOWS BECAUSE OF THE EXISTENCE OF FREE INTERFACES
- BASIC FLUID MECHANICAL MODELS WHICH ARE NEEDED TO DESIGN SUCH SYSTEMS AT REDUCED GRAVITY ARE LARGELY NON EXISTENT
- THE PENALTY FOR THIS IGNORANCE IS OVERDESIGN WITH THE COST OF EXTRA WEIGHT TO LIFT TO ORBIT AND POSSIBLE UNSAFE OPERATING CONDITIONS.
- SOUND MODELLING IS NEEDED ALONG WITH CAREFUL SPACE EXPERIMENTS IN ORDER THAT DESIGN METHODS BE AVAILABLE IN THE NEAR FUTURE.

#### EXAMPLES OF TECHNOLOGY NEEDS RELATED TO TWO PHASE FLOW

##### A. THE RANKIN CYCLE

- REACTOR/BOILER
  - TWO PHASE FLOW PRESSURE DROP ( BOILER FEED PUMP DESIGN)
  - FLOW PATTERN (TWO PHASE FLOW PRESSURE DROP)
  - BUBBLE SIZE (INTERFACIAL AREA AVAILABLE FOR HT TRANSFER)
  - SIZE AND VELOCITY OF LIQUID SLUGS ( STABILITY & VIBRATION; LOCAL HEAT TRANSFER COEFFICIENTS)
  - VOID FRACTION (HT TRANSFER COEFF AND HT TRANSFER AREA REQD)
  - BUBBLE COALESCENCE FREQUENCY AND INTERFACIAL WAVE MOTION (TRANSITION TO FILM BOILING AND BURNOUT)
- SEPARATOR
  - INLET FLOW PATTERN
- SEPARATOR-TURBINE TRANSFER LINE
  - PRESSURE DROP DURING ANNULAR FLOW (LINE SIZING)
  - THICKNESS OF CONDENSED FILM (CALC'N OF HEAT LOSS & P)
- TURBINE
  - DROP SIZE AND VELOCITY (TURBINE PERFORMANCE)
  - DROP DEPOSITION (BLADE DESIGN)
- TURBINE-CONDENSER TRANSFER LINE
  - FLOW PATTERN ( STABILITY AND VIBRATION)
  - PRESSURE DROP (LINE SIZING)
- CONDENSER
  - FLOW PATTERN AS GAS AND LIQUID RATIO CHANGE ALONG CONDENSER ( CONTROLS HT TRANSF. COEFF AND HEAT TRANSFER AREA)
  - PRESSURE DROP (CYCLE EFFICIENCY)

##### B. COOLDOWN OF CRYOGEN TRANSFER LINE

- DURING COOLDOWN TWO PHASE FLOW TAKES PLACE. PRESSURE DROP IS MUCH LARGER THAN FOR SINGLE PHASE FLOW AND CAPACITY OF THE LINE IS SMALLER.
- FLOW PATTERN IS IMPORTANT TO PREDICTING THE HT TRANSFER AND MUST BE KNOWN TO DESIGN THE TANK STORAGE DISTRIBUTORS.

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## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

#### *The Case for Two-Phase Gas-Liquid Flow Experiments In Space*

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#### TWO PHASE FLOW SPACE EXPERIMENTS WHICH ARE NEEDED

##### APPROACH:

- PHYSICAL AND MATHEMATICAL MODELLING IS UNDERTAKEN TO IDENTIFY THE FUNDAMENTAL PROCESSES CONTROLLING THE PHENOMENA
- SPACE EXPERIMENTS ARE DESIGNED TO TEST THESE UNDERLYING PREMISES BUT NOT TO OBTAIN EMPIRICAL CORRELATIONS
- MODELS ARE MODIFIED BASED ON THE PHYSICAL INSIGHTS OBTAINED FROM THE EXPTS. SUBSEQUENT RUNS IN SPACE UNDER DIFFERENT FLOW CONDITIONS, FLUID PROPERTIES OR GEOMETRY ARE USED TO TEST THE GENERALITY OF THE MODEL.

##### SOME EXPERIMENTAL SYSTEMS:

###### **A. THE ISOTHERMAL LOOP FOR MACRO MEASUREMENTS**

THIS SYSTEM IS TO BE DESIGNED TO FLOW GAS/LIQUID PAIRS OVER A WIDE RANGE OF RATES IN SEVERAL LINE DIAMETERS, INSTRUMENTED TO MEASURE FLOW PATTERN, TIME VARYING PRESSURE GRADIENT, CROSSECTIONAL AVERAGE VOIDS AND LOCAL FILM THICKNESS DURING ANNULAR FLOW. MUST BE SUITABLE FOR SEVERAL DIFFERENT FLUIDS TO STUDY THE EFFECT OF FLUID PROPERTIES. LOW PRESSURE SYSTEM. RELATIVELY SIMPLE INSTRUMENTATION AND DATA ACQUISITION SYSTEM.

###### **B THE ISOTHERMAL LOOP FOR MICRO MEASUREMENTS**

A CLOSED LOOP EQUIPPED WITH A LASER VELOCIMETER SYSTEM AND INSTRUMENTATION TO MEASURE BUBBLE AND DROP SIZE AND VELOCITY . INSTRUMENTATION IS MORE COMPLEX AND SOME DEVELOPMENT WILL BE NECESSARY TO ADAPT EXISTING INSTRUMENTS FOR SPACE.

###### **C. BOILING/CONDENSATION LOOP**

A CLOSED LOOP SYSTEM TO PERMIT THE STUDY OF TWO PHASE FLOW IN CONDITIONS OF CONDENSATION AND BOILING. THIS WILL INCLUDE LOCAL HEATX FLUX PROBES AS WELL AS PROBES FOR MACROSCOPIC TWO PHASE FLOW MEASUREMENTS.

##### NEEDED EMPHASIS:

EXPERIMENTS MUST BE DESIGNED AND EQUIPMENT INSTRUMENTED TO REVEAL UNDERLYING MECHANISM OF THE FLOW. OBTAINING DATA FOLLOWED BY EMPIRICAL CORRELATION WILL BE OF LIMITED USEFULNESS.

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## FLUID MANAGEMENT & PROPULSION SYSTEMS

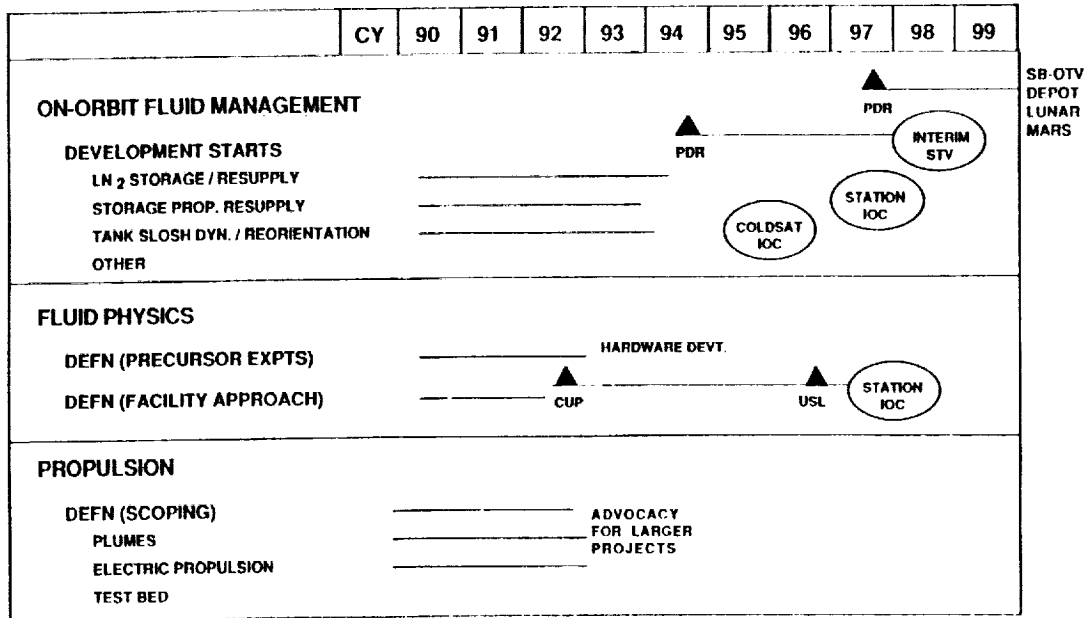
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### 4.3 Fluid Physics

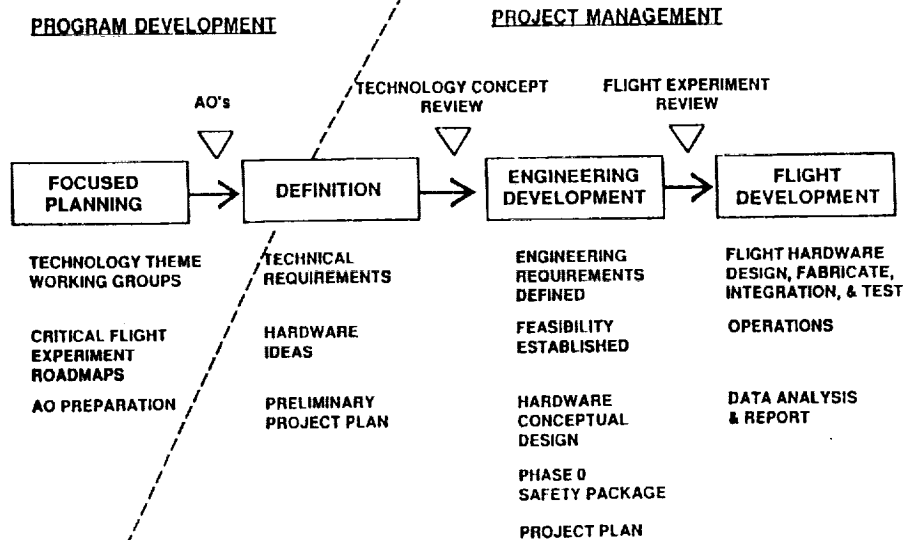
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## PROPOSED ROADMAP



## OAST IN-SPACE TECHNOLOGY PROGRAM PHASES



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# **FLUID MANAGEMENT & PROPULSION SYSTEMS**

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## 4.3 Fluid Physics

### *Fluid Management & Propulsion Systems*

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#### **WORKSHOP SPEAKERS**

On-Orbit Fluid Mgmt	John Aydelott John Schuster Leon Hastings	NASA LeRC General Dynamics NASA MSFC
Fluid Physics	Jack Salzman Dr. Franklin Dodge Dr. A. E. Dukler	NASA LeRC Southwest Res. Inst. U. Houston
Propulsion	James A. Kelley James Stone Dr. Charles Merkle	Jet Propulsion Lab OAST/RP Pennsylvania State U.

#### **PARTICIPANTS (ROUGHLY)**

	GOVERNMENT	INDUSTRY	UNIVERSITY
ON-ORBIT FLUID MGMT.	LeRC / COLDSAT MSFC JSC KSC	GENERAL DYNAMICS MARTIN MARIETTA BOEING AEROSPACE McDONNELL DOUGLAS LOCKHEED	U. TENN.
FLUID PHYSICS	LeRC / MICROGRAV.	SW RESEARCH INST. BATTELLE NW TELEDYNE BROWN FOSTER MILLER AM. SPACE TECH. EG&G IDAHO	U. HOUSTON U. TENN. U. MICHIGAN
PROPULSION	LeRC / ELECTRIC JPL / PLANETARY LeRC / CHEMICAL SPACE STATION	GRUMMAN ROCKETDYNE ROCKET RES. WESTINGHOUSE	PENN. STATE PRINCETON

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## FLUID MANAGEMENT & PROPULSION SYSTEMS

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### 4.3 Fluid Physics

#### *Fluid Management & Propulsion Systems*

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### ON-ORBIT FLUID MANAGEMENT THEME ELEMENT

#### POTENTIAL THRUSTS:

- PROVIDE ENHANCING TECHNOLOGY FOR SPACE STATION FREEDOM ORBITAL MANEUVERING VEHICLE, INTERIM STV, CO-ORBITING PLATFORM, AND COLD-SAT

AND / OR PROVIDE ENABLING TECHNOLOGY FOR ORBITAL DEPOT, RESUPPLY TANKER, LUNAR BASE, MARS EXPEDITION

#### CRITICAL TECHNOLOGIES

- LIQUID STORAGE
- LIQUID SUPPLY
- LIQUID TRANSFER
- FLUID HANDLING
- INSTRUMENTATION



#### AUDIENCE PRIORITIES

1. FLUID TRANSFER
2. MASS GAUGING
3. TVS / MIXING  
LAD PERFORMANCE  
FLUID DUMPING / TANK INERTING
4. LIQUID DYNAMICS / SLOSH
5. AUTOGENOUS PRESSURIZATION  
LONG TERM STORAGE

#### REPRESENTATIVE PROJECTS

- LIQUID NITROGEN STORAGE & SUPPLY EXPT
- STORAGE PROPELLANT RESUPPLY
- TANK SLOSH DYNAMICS & LIQ. REORIENTATION

- DEVT
- > SPEEDY DEFN & DEVT

#### REPRESENTATIVE PROJECTS

##### • LIQUID NITROGEN STORAGE AND SUPPLY EXPERIMENT

- ENHANCE ABILITY TO PROVIDE CRYO HEAT SINK FOR SPACE STATION EXPERIMENTS AND LAB FREEZER OPERATION FOR SPECIMEN PRESERVATION. REDUCE ANNUAL LIFE SUPPORT SYSTEM RESUPPLY TANKAGE WEIGHT TRANSPORTED TO STATION. SUPPORT DEVELOPMENT OF ISTV AND COLD-SAT.

- |                             |                                   |
|-----------------------------|-----------------------------------|
| • CARGO EXPT                | • STORAGE & SUPPLY IN LOW GRAVITY |
| • LN, STORAGE DEWAR         | • VENT TANK & DUMP OVERBOARD      |
| • PASSIVE TVS, MIXER        | • N <sub>2</sub> & HE PRESSURANTS |
| • LIQUID ACQUISITION DEVICE | • GAGING INSTRUMENTATION          |

##### • STORABLE PROPELLANT RESUPPLY EXPERIMENT

- ENHANCE ABILITY FOR ON-ORBIT SERVICING OF OMV AND CO-ORBITING PLATFORM. SUPPORT OTHER BI-PROP USERS AND DEVELOPMENT OF COLD-SAT.

- |                            |                          |
|----------------------------|--------------------------|
| • CARGO ON MIDDECK EXPT    | • LAD PERFORMANCE & FILL |
| • REFEREE FLUID            | • TANK VENTING           |
| • FILL STORABLE PROP. TANK | • MASS GAUGING           |

##### • TANK SLOSH DYNAMICS AND LIQUID REORIENTATION

- ENHANCE OMV AND ISTV PERFORMANCE BY INCREASING DYNAMIC STABILITY, PROPELLANT UTILIZATION. REDUCE REQUIRED DESIGN MARGINS.

- |                      |  |
|----------------------|--|
| • MIDDECK EXPERIMENT | • MULTIPLE TANKS (SIZE, SHAPE)         |
| • REFEREE FLUID      | • SLOSH & REORIENT UNDER IMPOSED LOW-G |
|                      | • VIDEO                                |

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# FLUID MANAGEMENT & PROPULSION SYSTEMS

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## 4.3 Fluid Physics

### Fluid Management & Propulsion Systems

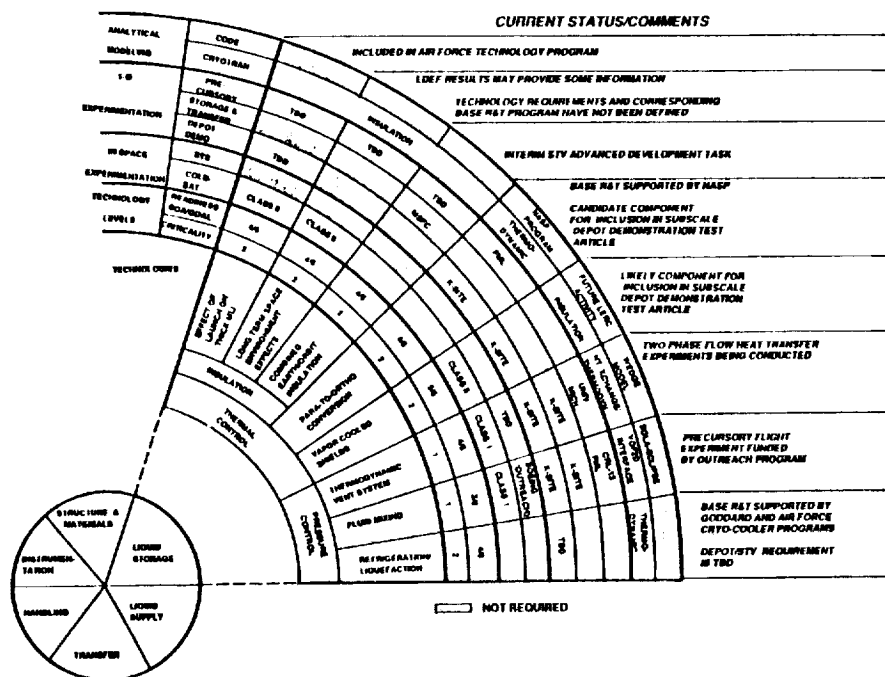
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#### CRITICAL IN-SPACE TECHNOLOGY NEEDS

- EFFECT OF LAUNCH ENVIRONMENT ON THICK MULTILAYER INSULATION
- LONG TERM SPACE ENVIRONMENT EFFECTS ON INSULATION (DEBRIS, MICROMETEORIDS AND ATOMIC OXYGEN)
- COMBINED EARTH/ORBIT INSULATION
- COOLING ENHANCEMENT PROVIDED BY PARA-TO ORTHO CONVERSION
- MULTIPLE/COUPLED VAPOR COOLED SHIELDS
- THERMODYNAMIC VENT SYSTEM PERFORMANCE
- FLUID MIXING FOR STRATIFICATION CONTROL
- REFRIGERATION/BOILBACK SYSTEM DEMONSTRATION (INCLUDING CONDENSATE COLLECTION)
- AUTOGENOUS (INCLUDING PARA/ORTHO COMPOSITION) PRESSURIZATION SYSTEM
- HELIUM SUPPLY/PRESSURIZATION
- MECHANICAL TRANSFER (PUMPS/COMPRESSORS)
- FINE MESH SCREEN LIQUID ACQUISITION DEVICE (LAD) EXPULSION EFFICIENCY
- REORIENTATION & OUTFLOW VIA IMPULSIVE ACCELERATION
- REORIENTATION & OUTFLOW UNDER CONSTANT LOW GRAVITY CONDITIONS
- THERMAL EFFECTS ON LAD PERFORMANCE
- THERMAL SUBCOOLING OF LIQUID OUTFLOW
- TRANSFER LINE CHILL DOWN
- TANK CHILL DOWN WITH SPRAY
- NO VENT FILL
- LIQUID ACQUISITION DEVICE (LAD) FILL
- LOW GRAVITY VENTED FILL
- LIQUID DYNAMICS/SLOSH CONTROL
- FLUID DUMPING/TANK VENTING AND INERTING
- EARTH TO ORBIT TRANSPORT AS SUBCOOLED LIQUID OR LIQUID/SOLID MIXTURE (SLUSH)
- QUANTITY GAGING
- MASS FLOW/QUALITY METERING
- LEAK DETECTION (IN SPACE TESTING REQUIREMENT CONCEPT SPECIFIC)
- LIQUID/VAPOR SENSORS
- COMPOSITE (LIGHT WEIGHT) VACUUM JACKET
- LOW THERMAL CONDUCTIVITY COMPONENTS
- LOW PRESSURE TANKAGE
- CONTAMINATION/DEGRADATION OF LIQUID ACQUISITION DEVICE

- IN<sub>2</sub> RESUPPLY SYSTEM DEMONSTRATION (SYSTEM DEMO ADDRESSES SEVERAL TECHNOLOGY NEEDS)

IN SPACE EXPERIMENTATION NEEDED



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## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

### Fluid Management & Propulsion Systems

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#### IN-SPACE TESTING OPPORTUNITIES

Technology Category	Critical Data Needed By		Deployment Options		
	Enable	Enhance	Space Shuttle	ELV	Space Station
• Liquid Storage					
• Thermal Control Systems					
• Degradation of Material	2003?	1997	Deployment /Recovery	Deployment	After 1997
• Pressure Control Systems					
• TVS Performance	1997	1994	Alternate Cryogen	Hydrogen	After 1997
• Fluid Mixing for Stratification Control	1997	1994	Alternate Fluid	Hydrogen	After 1997
• Liquid Supply					
• Pressurization System Perf.					
• Autogenous	1997	1994	Alternate Cryogen	Hydrogen	After 1997
• Helium	1994		Alternate Cryogen	Hydrogen	After 1997
• Fluid Acquisition					
• Fine Mesh Screen LAD Performance	1997		Alternate Fluid	Hydrogen	After 1997
• Fluid Settling & Outflow under Low G		1994	Alternate Fluid		
• Fluid Settling & Outflow under Impulsive Acceleration		1994	Alternate Fluid		
• Liquid Transfer					
• Transfer Line Chiddown	1997		Alternate Cryogen	Hydrogen	After 1997
• Tank Chiddown with Spray	1997		Alternate Cryogen	Hydrogen	After 1997
• No-Vent Fill	1997		Alternate Cryogen	Hydrogen	After 1997
• LAD Fill		1997	Alternate Fluid	Hydrogen	After 1997
• Low G Vented Fill		1997	Alternate Cryogen	Hydrogen	After 1997
• Fluid Handling					
• Liquid Dynamics/Slosh Control		1994	Alternate Fluid		
• Fluid Dumping & Tank Inerting	1997		Alternate Cryogen	Hydrogen	After 1997
• Advanced Instrumentation					
• Quantity Gauging	1997	1994	Alternate Fluid	Hydrogen	After 1997

#### TECHNOLOGY NEEDS

##### MISSION CRITICALITY

Technology Category	Space-Based STV		Resupply Tanker		Mars Expedition	
	Interim STV	Orbital Depot	Orbital Depot	Lunar Base	Lunar Base	Mars Expedition
• Liquid Storage						
• Thermal Control Systems						
• Degradation of Material		Enhance	Enhance		Enhance	Enable
• Effect of Launch Env on Thick MLI	Enable	Enable	Enable	Enhance	Enable	Enable
• Combined Foam/MLI Sys	Enhance		Enhance	Enhance	Enhance	Enable
• Para/Ortho Conversion			Enhance		Enhance	Enable
• Multiple/Coupled VCS			Enhance		Enhance	Enable
• Pressure Control Systems						
• TVS Performance	Enhance	Enhance	Enable	Enhance		Enable
• Fluid Mixing for Stratification Control	Enhance	Enhance	Enable	Enhance		Enable
• Refrigeration/Refuefaction			Enhance		Enhance	Enable ?
• Liquid Supply						
• Pressurization System Perf.						
• Autogenous	Enhance	Enable	Enable	Enhance	Enable	Enable
• Helium	Enable					
• Mech. (Pumps/Comp.)			Enhance	Enhance	Enhance	Enhance
• Fluid Acquisition						
• Fine Mesh Screen LAD Performance		Enhance ?	Enable	Enable		Enable
• Fluid Settling & Outflow under Low G Conditions	Enhance	Enhance	Enhance	Enhance		Enhance
• Fluid Settling & Outflow under Impulsive Accel.	Enhance	Enhance		Enhance		Enhance
• Impact of Heat Addition on LAD Performance		Enhance	Enhance ?	Enhance		Enhance
• Thermal Subcooling of Liquid Outflow			Enhance	Enhance	Enhance	Enhance

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## FLUID MANAGEMENT & PROPULSION SYSTEMS

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### 4.3 Fluid Physics

#### *Fluid Management & Propulsion Systems*

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### FLUID PHYSICS THEME ELEMENT

#### POTENTIAL THRUST:

ENHANCE FUNDAMENTAL UNDERSTANDING OF FLUID BEHAVIOR/DYNAMICS IN  
REDUCED GRAVITY TO ESTABLISH RELIABLE PREDICTIVE MODELS & DATA BASES FOR  
ADVANCED SYSTEMS DEVELOPMENT

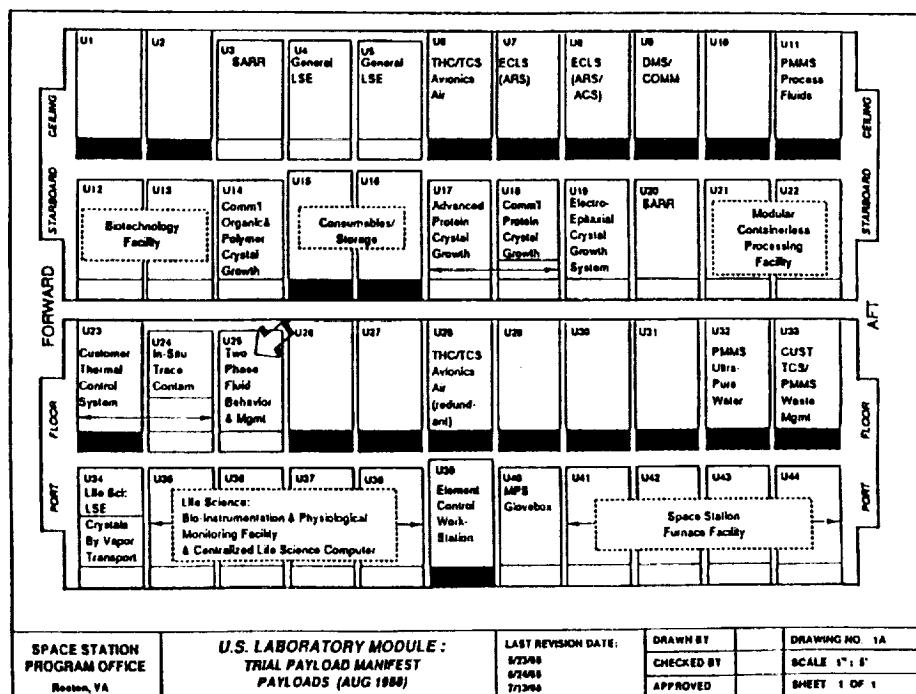
AND / OR

INITIATE DEFINITION & PRECURSOR FLIGHT EXPTS FOR SPACE STATION FLUID  
PHYSICS FACILITY (1997 IOC, 1992 CUP)

#### REPRESENTATIVE PROJECTS:

1. ISOTHERMAL MULTIPHASE FLOW
1. LIQUID-VAPOR INTERFACES
2. POOL/FLOW BOILING
2. CONDENSATION / EVAPORATION
3. ADVANCING LIQUID FRONTS
3. BUBBLE / DROPLET DYNAMICS

TYPICALLY:  
UNIVERSITY PI  
HARDWARE DEVT CONTRACT  
FACILITY OPTIONS



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## FLUID MANAGEMENT & PROPULSION SYSTEMS

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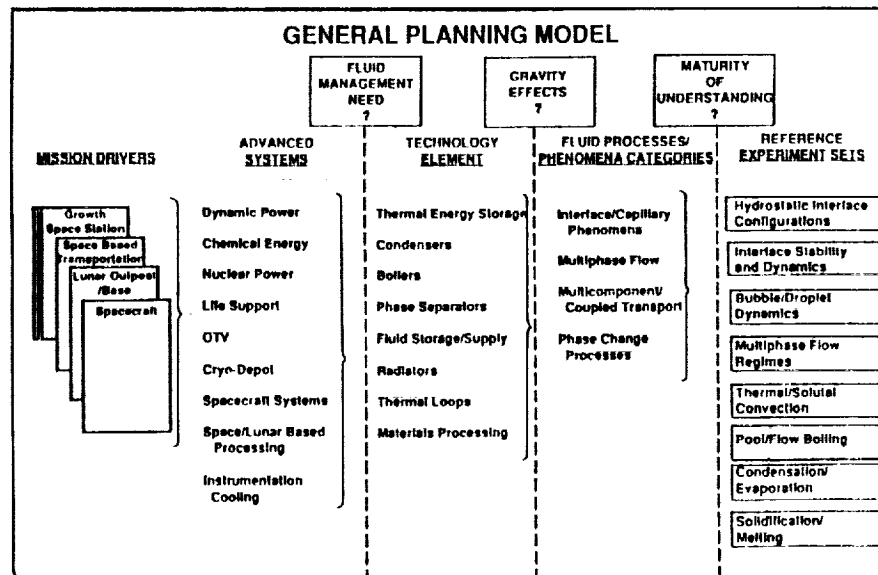
### 4.3 Fluid Physics

### Fluid Management & Propulsion Systems

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#### CRITICAL IN-SPACE TECHNOLOGY NEEDS

- **HYDROSTATIC INTERFACE CONFIGURATIONS**
  - THE BULK LIQUID LOCATION & CONFIGURATION OF EQUILIBRIUM LIQUID-GAS INTERFACE AS A FUNCTION OF FLUID PROPERTIES, VESSEL GEOMETRY & SIZE, GRAVITY LEVEL, & SYSTEM INITIAL CONDITIONS
- **INTERFACE STABILITY & DYNAMICS**
  - RESPONSE OF A LOW-G LIQUID VAPOR INTERFACE TO MECHANICAL & THERMAL DISTURBANCES & ITS EFFECT ON BULK LIQUID MOTION
- **BUBBLE DROPLET DYNAMICS**
  - THE BUOYANCY AND/OR THERMALLY DRIVEN MOTION OF SINGLE BUBBLE/DROPLET UNDER LOW-G CONDITIONS & INTERACTIONS BETWEEN MULTIPLE BUBBLES/DROPLETS INCLUDING COALESCENCE/BREAKUP
- **MULTIPHASE FLOW REGIMES**
  - FLOW REGIME PATTERNS & CHARACTERISTICS GENERATED BY FORCED ADIABATIC FLOW OF LIQUID VAPOR OR IMMISCIBLE LIQUID MIXTURES THRU CONDUITS & FITTINGS AS A FUNCTION OF FLUID PROPERTIES, FLOW RATES, CONDUIT/FITTING GEOMETRY & SIZE, AND GRAVITY LEVEL
- **THERMAL/SOLUTAL CONVECTION**
  - HEAT & MASS TRANSFER GENERATED BY BUOYANCY DRIVEN FLOWS RESULTING FROM THERMAL &/OR CONCENTRATION GRADIENTS UNDER REDUCED GRAVITY CONDITIONS
- **POOL/FLOW BOILING**
  - ONSET OF NUCLEATE BOILING & SUBSEQUENT BUBBLE DYNAMICS AS A FUNCTION OF SYSTEM SATURATION, HEAT FLUX, FLUID PROPERTIES, HEATER GEOMETRY, & G-LEVEL FOR BOTH STAGNANT & LIQUID FLOW CONDITIONS
- **CONDENSATION/EVAPORATION**
  - CONDITIONS FOR CONDENSATION/EVAPORATION OF LIQUID-VAPOR INTERFACES & ITS EFFECTS ON INTERFACE STABILITY/ DYNAMICS UNDER LOW-G CONDITIONS FOR BOTH STAGNANT & VAPOR FLOW CONDITIONS
- **SOLIDIFICATION/MELTING**
  - DYNAMIC BEHAVIOR OF THE SOLID FLUID FRONT DURING SOLIDIFICATION &/OR MELTING UNDER LOW-G CONDITIONS WITH SPECIAL EMPHASIS ON VOID FORMATION & DYNAMICS DUE TO VOLUME CHANGES
- **SHAPE & STABILITY OF LIQUID VAPOR INTERFACE & THE LOCATION OF THE BULK LIQUID VOLUME IN A TANK IN REDUCED GRAVITY AS FUNCTIONS OF TANK GEOMETRY, FLUID PROPERTIES, TANK SURFACE PROPERTIES, LIQUID FILL LEVEL, AND G-LEVEL**
- **EFFECTS OF SURFACE TENSION ON LIQUID MOTION IN SPINNING TANKS**
- **SURFACE PHYSICS FOR SURFACES IN MOTION AT THE SOLID-LIQUID VAPOR CONTACT LINE IN REDUCED GRAVITY**
- **HEAT TRANSFER AT THE ONSET OF BOILING IN REDUCED GRAVITY - DETERMINE BASIC SHAPE OF THE BOILING CURVE**
- **DISTRIBUTION OF BUBBLES GENERATED BY DISPERSION DEVICES IN A TURBULENT LIQUID FLOW AT STEADY REDUCED G-LEVEL**
- **EFFECTS OF GRAVITY ON HEAT TRANSFER FOR FORCED CONVECTIVE BOILING, ESPECIALLY AT TRANSITION TO FILM BOILING AND BURNOUT**
- **FLUID MECHANICS OF & HEAT TRANSFER TO A THIN LIQUID FILM MOVING ALONG A SOLID SURFACE UNDER THE INFLUENCE OF INTERFACIAL GAS SHEAR, INCLUDING THE STABILITY OF THIN FILMS & THE PROCESS OF DROP FORMATION FROM THE INTERFACE AS A RESULT OF FLOW ACROSS THE LIQUID SURFACE**
- **PRESSURE DROP & ITS TIME VARIATION FOR TWO PHASE SLUG FLOW IN REDUCED GRAVITY FOR STEADY FLOW CONDITIONS OR DURING VARIATIONS IN FLOW RATE & VARYING G-LEVELS**
- **SHAPE & RATE OF ADVANCE OF A LIQUID FRONT MOVING ALONG A SOLID SURFACE WHICH IS BEING THERMALLY QUENCHED IN REDUCED GRAVITY**



Theme 4 of 8

## FLUID MANAGEMENT & PROPULSION SYSTEMS

Theme 4 of 8

### 4.3 Fluid Physics

#### *Fluid Management & Propulsion Systems*

Lynn M. Anderson  
NASA Lewis Research Center

#### **EXAMPLE: OTV**

**Fluid Process:** Interface configuration and stability

**Problems:**

- gas-free liquid transfer
- quantity-gaging - liquid location is unknown so elaborate, heavy, complex, and limited accuracy systems are used.

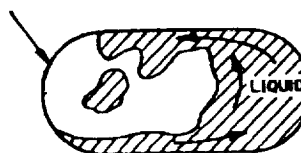
**Technology Need:** Accurate prediction of interface location so a simple, reliable, accurate gaging system can be used.

**Fluid Process:** Interface dynamics and bulk liquid motion.

**Problem:** Docking causes large impulsive accelerations. The liquid undergoes gross motions which degrade control and increase liquid transfer time.

**Technology Need:** Validate method (CFD code) to predict large free-surface motions in low-g and the duration of such motions

DOCKING IMPULSE



## PROPULSION THEME ELEMENT

### POTENTIAL THRUST:

DEFINITION & ENGINEERING DEVELOPMENT OF PROPULSION FLIGHT PROJECTS,

- MAY BE BEYOND OUTREACH SCOPE DUE TO COST, CARRIER COMPLEXITY, MULTI-AGENCY SPONSORSHIP

### REPRESENTATIVE PROJECTS:

1. PLUME CHARACTERISTICS & IMPACT
2. ELECTRIC PROPLUSION SPACE TEST
3. MAN TENDED, MULTIDISCIPLINE SPACE TESTBED

Theme 4 of 8

**FLUID MANAGEMENT & PROPULSION SYSTEMS**

Theme 4 of 8

4.3 Fluid Physics

***Fluid Management & Propulsion Systems***

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NASA Lewis Research Center

**RECOMMENDATION PROCESS FINDINGS**

<u>TOPIC</u>	<u>NUMBER OF RECOMMEN.</u>	<u>AVERAGE SCORE (1 TOP PRTY)</u>	<u>CONSENSUS PRIORITY</u>
PLUME IMPACTS & CHARACTERISTICS	10	1.2	X
ELECTRIC PROPULSION SPACE TEST	9	1.9	X
MULTIDISCIPLINE SPACE TEST BED	7	2.4	X
LARGE NOZZLE (5-25K LB.) SPACE EVALS	1	1	
FAULT DIAGNOSTICS & MAINTENANCE	1	1	
ENVIRONMENTAL PROTECTION	1	2	
IN-SPACE ENGINE RESTARTS	1	6	
VACUUM WELDING	1	7	
IN-SITU PROPELLANTS	1	8	

**PROGRAMMATIC CONCERNS**

**SCOPE**

- DOLLAR LIMITS/GUIDELINES
- TIME CONSTRAINTS/FLEXIBILITY WITH DISCIPLINE & INSTITUTION
- TECHNOLOGY READINESS LEVELS (SYSTEM DEMOS?)
- FROM DEFINITION THROUGH DEVELOPMENT?
- FACILITY CONCEPT WITH MULTIPLE INVESTIGATORS

**SELECT CRITERIA**

- "SPREADING DOLLARS ACROSS THEMES"?
- PROJECTS WHICH SPAN SUBTHEMES
- HIGH DOLLARS ON ONE ACTIVITY PRECLUDES OTHERS?

**COMMITMENT**

- UNIVERSITY INVOLVEMENT

Theme 5 of 8

## AUTOMATION AND ROBOTICS

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

**Antal K. Bejczy**  
Jet Propulsion Laboratory

## ORGANIZATION

**THEME LEADER:** ANTAL K. BEJCZY, JPL

**COMMITTEE:** THOMAS S. DOLLMAN, MSFC  
HENRY LUM, ARC  
ALFRED J. MEINTEL, JR., LaRC  
CHARLES R. PRICE, JSC  
LLOYD R. PURVES, GSFC  
DOUGLAS A. ROHN, LeRC  
JAMES P. JENKINS, NASA HQ, OAST/RC  
(EX OFFICIO)

**SUBTHEMES & THEME GROUPS:**

1. ROBOTICS
2. TELEOPERATION
3. ARTIFICIAL INTELLIGENCE

## THEME SESSION OBJECTIVES

### PURPOSE

- IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES FOR AUTOMATION & ROBOTICS, BY CONSIDERING SUBTHEME DETAILS, WHICH
  - ● ARE CRITICAL FOR FUTURE U.S. SPACE PROGRAMS
  - ● REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
- GENERATE COMMENTS AND SUGGESTIONS FROM AEROSPACE COMMUNITY ON OAST IN-STEP PLANS

### PRODUCT

- PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS, RECOMMENDED BY AEROSPACE COMMUNITY

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

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Jet Propulsion Laboratory

### **THEME DESCRIPTION**

- **SCOPE**

FULL SPECTRUM OF TELEOPERATION, ROBOTICS AND ARTIFICIAL INTELLIGENCE COMPONENTS, SUBSYSTEMS AND SYSTEMS AS THEY RELATE TO SPACE MISSIONS, INCLUDING HUMAN OPERATOR FUNCTIONS IN THESE SYSTEMS

- **GOAL**

PROVIDE THE TECHNOLOGY AND UNDERSTANDING OF ALL THREE SUBTHEMES NEEDED TO ENSURE PRODUCTIVE AND SAFE APPLICATION OF INCREASINGLY AUTOMATED ROBOTIC AND SYSTEM CAPABILITIES IN SPACE MISSIONS UNDER REMOTE HUMAN OPERATOR SUPERVISION, INCLUDING THE UNDERSTANDING OF HUMAN PERFORMANCE CAPABILITIES IN THESE SYSTEMS

### **BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT**

- **SUMMARY OF A&R THEME FROM 1985 WILLIAMSBURG, VA WORKSHOP (SEE APPENDIX)**

- **ACCOMPLISHMENTS SINCE 1985**

- IN-REACH ACTIVITIES
- OUT-REACH ACTIVITIES
- EXPERIMENTS IN PREPARATIONS
  - SHUTTLE RMS FTS/DEXTRIOUS MANIPULATION
  - TRIIFEX/ROTEX
  - S/S FTS



Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

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### **DESCRIPTION OF SUBTHEME 1: ROBOTICS**

#### **TECHNOLOGY ELEMENTS**

- ROBOT MECHANISMS AND ACTUATORS
- ROBOT SENSING
- ROBOT CONTROLS
- ROBOT PROCESSING AND ITS ARCHITECTURE
- ROBOT SYSTEM CONCEPTS AND DESIGNS

INCLUDING REDUNDANCY IN ROBOTIC SYSTEMS, TOGETHER WITH RELIABILITY AND FAULT TOLERANCE REQUIREMENTS IN SPACE SYSTEMS

#### **SUBTHEME OBJECTIVES**

DEVELOP A VALIDATED TECHNOLOGY BASE FOR ABOVE ELEMENTS, TAKING INTO ACCOUNT SPACE APPLICATION AND SPACE ENVIRONMENTAL CONDITIONS AND MISSION CONSTRAINTS

### **DESCRIPTION OF SUBTHEME 2: TELEOPERATION**

#### **TECHNOLOGY ELEMENTS**

- MULTI-MODE OPERATOR INTERFACES TO TELEROBOTS
- INTELLIGENT DISPLAYS
- HIERARCHICAL CONTROL/INFORMATION ARCHITECTURES
- VISUAL PERCEPTION SYSTEMS
- COMMUNICATION TIME DELAY

INCLUDING SUPERVISORY COMMAND LANGUAGES, TRADED/SHARED MANUAL/COMPUTER CONTROLS AND THE USE OF EXPERT SYSTEMS BY HUMAN OPERATORS

#### **SUBTHEME OBJECTIVES**

DEVELOP A VALIDATED TECHNOLOGY BASE FOR EFFICIENT AND SAFE UTILIZATION OF HUMAN OPERATOR CAPABILITIES IN DIRECT OR SUPERVISORY CONTROL OF TELEROBOTS, TAKING INTO ACCOUNT THE EFFECTS OF SPACE CONDITIONS (MICROGRAVITY, ETC.) AND COMMUNICATION TIME DELAYS ON OPERATOR BEHAVIOR AND PERFORMANCE, AND ALSO CONSIDERING THE HANDLING OF SINGULAR OR UNEXPECTED TASKS

### **DESCRIPTION OF SUBTHEME 3: ARTIFICIAL INTELLIGENCE**

#### **TECHNOLOGY ELEMENTS**

- OPERATIONS AND CONTROL PLANNING/COORDINATION
- PERFORMANCE MONITORING OF COMPLEX SYSTEMS
- ERROR DETECTION AND RECOVERY
- MULTI-SENSOR DATA INTERPRETATION
- OPERATOR INTERACTION WITH EXPERT SYSTEMS

USING EXISTING AND EVOLVING CAPABILITIES OF ARTIFICIAL OR MACHINE INTELLIGENCE TECHNIQUES

#### **SUBTHEME OBJECTIVES**

DEVELOP A VALIDATED TECHNOLOGY BASE FOR INCREASED LEVEL OF INTELLIGENT AUTOMATION APPLICABLE TO SPACE MISSIONS AND OPERATIONS, INCLUDING TELEROBOTIC MISSIONS AND OPERATIONS, TAKING INTO ACCOUNT SPACE OPERATIONS CONSTRAINTS

Theme 5 of 8

## AUTOMATION AND ROBOTICS

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

Antal K. Bejczy  
Jet Propulsion Laboratory

### THEME SESSION AGENDA

9:45 A.M.

11:45 A.M.

#### SUBTHEME: ROBOTICS

SPEAKER 1 (30 min)  
SPEAKER 2 (30 min)  
SPEAKER 3 (30 min)  
DISCUSSION (30 min)

1:00 P.M.

3:00 P.M.

#### SUBTHEME: TELEOPERATION

SPEAKER 1 (30 min)  
SPEAKER 2 (30 min)  
SPEAKER 3 (30 min)  
DISCUSSION (30 min)

3:15 P.M.

5:15 P.M.

#### SUBTHEME: ARTIFICIAL INTELLIGENCE

SPEAKER 1 (30 min)  
SPEAKER 2 (30 min)  
SPEAKER 3 (30 min)  
DISCUSSION (30 min)

#### SPEAKERS & PANEL

1. A. MEINTEL, LARC  
2. T. DEPKOVICH/J. SPOFFORD, MARTIN MARIETTA SPACE SYSTEMS  
3. PROFESSOR D. TESAR, UNIVERSITY OF TEXAS, AUSTIN  
PANEL: SUBTHEME SPEAKERS AND: PROFESSOR J. DUFFY, UNIV. OF FLORIDA; PROFESSOR G. SARIDIS, RPI; F. GARCIA, IBM; S. HARRIS, ODETICS.

1. C. PRICE, JSC  
2. P. PIERSON, GENERAL ELECTRIC  
3. PROFESSOR T. SHERIDAN, MIT  
PANEL: SUBTHEME SPEAKERS AND: L. JENKINS, JSC; PROFESSOR L. STARK, UC BERKELEY; PROFESSOR J. STAUDHAMMER, UNIVERSITY OF FLORIDA.

1. N. SLIWA/P. FRIEDLAND, ARC  
2. D. ROSENBERG ISX, INC.  
3. PROF. R. CANNON, STANFORD UNIV.  
PANEL: SUBTHEME SPEAKERS AND: R. SIMPSON, DARPA; J. DICKERSON, MCDONNELL-DOUGLAS SPACE DIV.

### THEME DISCUSSIONS

#### ● AFTER EACH SUBTHEME SESSION

- OPEN 30 min DISCUSSION WITH AUDIENCE & THEME LEADER/SPEAKERS/PANEL
  - QUESTIONS & ANSWERS
  - IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE
- AUDIENCE PRIORITIZATION OF CRITICAL TECHNOLOGIES

#### ● JOINT THEME DISCUSSION, THURSDAY 8:30-10:45 A.M.

- DISCUSSION BETWEEN AUDIENCE & ALL THEME ELEMENT SPEAKERS
- RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

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### **PRIORITIZATION CRITERIA (LISTED IN ORDER OF IMPORTANCE)**

#### **1. CRITICAL ENABLING TECHNOLOGIES**

- TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U.S. SPACE MISSIONS

#### **2. COST REDUCTION TECHNOLOGIES**

- TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY (e.g., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)

#### **3. BROAD APPLICATION TECHNOLOGIES**

- TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS

#### **4. REQUIRE IN-SPACE VALIDATION**

- TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR VALIDATION OR EXPERIMENTATION

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

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Jet Propulsion Laboratory

**SUMMARY OF  
AUTOMATION & ROBOTICS THEME FROM  
1985 WILLIAMSBURG, VA, IN-SPACE RT&E WORKSHOP**

— QUOTED FROM WORKSHOP EXECUTIVE SUMMARY —

*Quotes from the 1985 Williamsburg, Virginia, RT&E Workshop*

**AUTOMATION AND ROBOTICS  
OBJECTIVES/CAPABILITIES**

o **VALIDATE ROBOTIC IN-SPACE OPERATIONS CAPABILITY**

- DOCKING - 1988
- SATELLITE SERVICING - 1990
- STRUCTURAL ASSEMBLY - 1992
- IVA ASSISTANT - 1996
- EVA ASSISTANT - 2000

o **EVOLVE ROBOTIC IN-SPACE OPERATIONS CAPABILITY**

- TELEPRESENCE - 1990
- SUPERVISORY CONTROL - 1994
- AUTONOMOUS OPERATIONS - 1998

o **SYSTEM AUTONOMY CAN BE DEMONSTRATED ON GROUND**

Theme 5 of 8

## AUTOMATION AND ROBOTICS

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

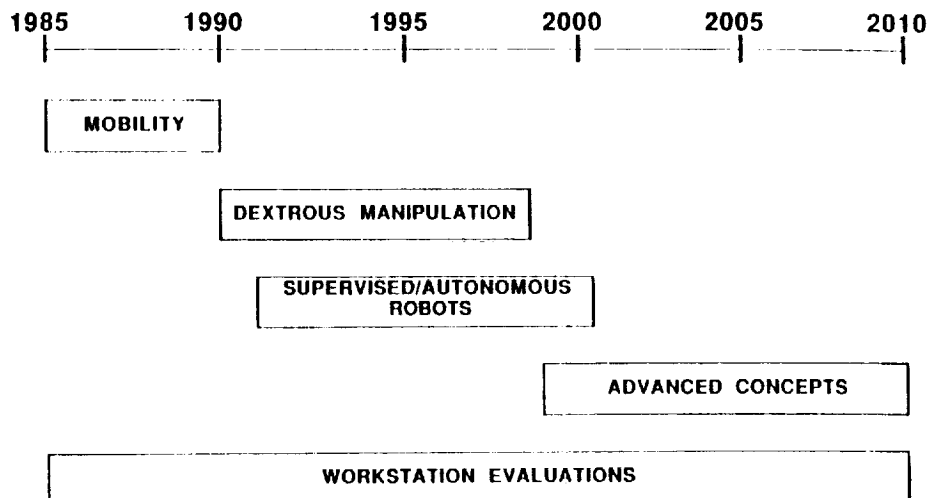
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Jet Propulsion Laboratory

### WHY IN-SPACE EXPERIMENTS

- o EVALUATE ZERO "G" VS. ONE "G" DYNAMICS FOR:
  - MECHANICAL CONFIGURATIONS
  - PROXIMITY OPERATIONS
  - FLUIDS, SOLIDS, GASES
- o DEVELOP DESIGN/OPERATIONAL DATA BASE
- o VALIDATE PROTO FLIGHT HARDWARE/SOFTWARE/ PROCESSES
- o EVALUATE MAN/MACHINE PERFORMANCE ON-ORBIT
- o EVALUATE GROUND MODELS/SIMULATIONS
- o EVALUATE LONG TERM SPACE EFFECTS ON SYSTEMS

*Quotes from the 1985 Williamsburg, Virginia, RT&E Workshop*

### AUTOMATION AND ROBOTICS EXPERIMENT THRUSTS



Theme 5 of 8

# **AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

*Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)*

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Jet Propulsion Laboratory

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
<ul style="list-style-type: none"> <li>• SINGLE ARM TELEOPERATOR</li> </ul>	<ul style="list-style-type: none"> <li>• DUAL ARM TELEOPERATOR COORDINATION</li> </ul>	<ul style="list-style-type: none"> <li>• MULTI-ARM COORDINATION</li> </ul>
<ul style="list-style-type: none"> <li>• TELEOPERATION FROM EARTH</li> <li>• COMBINED TRANSLATION/MANIPULATION</li> </ul>	<ul style="list-style-type: none"> <li>• TELEPRESENCE</li> </ul>	<ul style="list-style-type: none"> <li>• AUTONOMOUS ROBOTICS</li> <li>• MULTIPLE ROBOT COORDINATION</li> </ul>
<ul style="list-style-type: none"> <li>• FIXED ON-STATION RMS</li> <li>• DOCKING</li> </ul>	<ul style="list-style-type: none"> <li>• MOBILE ON STATION RMS</li> <li>• TELEOPERATED FREE-FLYING OPERATIONS</li> </ul>	<ul style="list-style-type: none"> <li>• FREE-FLYING AUTONOMOUS PROXIMITY OPERATIONS</li> </ul>
	<ul style="list-style-type: none"> <li>• FREE-FLYER AND DUAL-ARM COLLISION AVOIDANCE</li> <li>• CAD-DRIVEN POSITION REGISTRATION (ON S/S)</li> </ul>	<ul style="list-style-type: none"> <li>• MULTIPLE ARM COLLISION AVOIDANCE</li> </ul>
<ul style="list-style-type: none"> <li>• END-EFFECTOR DEFINITION</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>• MECHANICAL ASSEMBLY PROCESS</li> </ul>	<ul style="list-style-type: none"> <li>• JOINTING</li> </ul>	<ul style="list-style-type: none"> <li>• WELDING</li> </ul>
<ul style="list-style-type: none"> <li>• WORK STATION HW/SW/MM INTERFACES</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>• SENSOR ACCOMMODATIONS</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>• SPACE EFFECTS ON TELEOP. CAPABILITY</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>
	<ul style="list-style-type: none"> <li>• ZERO G MATERIALS HANDLING</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>

*Quotes from the 1985 Williamsburg, Virginia, RT&E Workshop*

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
<ul style="list-style-type: none"> <li>• FAILURE DETECTION</li> <li>• FAILURE ISOLATION</li> <li>• FAILURE TOLERANCE</li> </ul>	<ul style="list-style-type: none"> <li>• FAULT TOLERANT (EVOLVING)</li> <li>• FAULT REPAIR</li> </ul>	<ul style="list-style-type: none"> <li>• FAULT REPAIR (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>• ADVANCED AUTOMATION SOFTWARE ALGORITHMS</li> </ul>	<ul style="list-style-type: none"> <li>• REAL-TIME PLANNING</li> <li>• INDEPENDENT EXPERT</li> </ul>	<ul style="list-style-type: none"> <li>• INTERACTIVE AI/EXPERT SYSTEMS</li> </ul>
<ul style="list-style-type: none"> <li>• IMPROVED SATELLITE SERVICING TOOLS</li> </ul>	<ul style="list-style-type: none"> <li>• TELEOPERATOR SATELLITE SERVICING</li> </ul>	<ul style="list-style-type: none"> <li>• AUTONOMOUS SATELLITE SERVICING &amp; REPAIR BY ROBOTS</li> </ul>
	<ul style="list-style-type: none"> <li>• ROBOTIC INSPECTION (SENSOR DEPENDENT)</li> </ul>	<ul style="list-style-type: none"> <li>• ROBOTS REPAIR BY ROBOTS</li> </ul>
<ul style="list-style-type: none"> <li>• WORKLOAD POWER CONSUMPTION EXPERIMENTS</li> </ul>		
<ul style="list-style-type: none"> <li>• ROBOTIC VISION AND IMAGERY OPTIMIZATION</li> </ul>	<ul style="list-style-type: none"> <li>• SPACE EFFECTS ON VISION SYSTEMS</li> </ul>	
<ul style="list-style-type: none"> <li>• AUTONOMOUS ORBIT TRANSFER</li> </ul>		
<ul style="list-style-type: none"> <li>• COMPLIANCE TECHNIQUES</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>• MASS MOVEMENTS STUDIES</li> </ul>	<ul style="list-style-type: none"> <li>• MOMENTUM COORDINATION</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>
<ul style="list-style-type: none"> <li>• VOICE CONTROL/INTERACTION</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>	<ul style="list-style-type: none"> <li>• (EVOLVING)</li> </ul>

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

***Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)***

**Antal K. Bejczy**  
Jet Propulsion Laboratory

**AUTOMATION AND ROBOTICS**

**EXPERIMENT LIST**

1988	PROXIMITY MANEUVERING
1989	TELEOPERATED MANEUVERING (MMU)
1990	SMART FRONT END TECHNOLOGY
1992	SATELLITE SERVICING
1994/6	SUPERVISORY STRUCTURAL ASSEMBLY
1996	IVA ROBOT
2000	AUTONOMOUS SPACE ROBOT
2010	SPACE SPIDER

CONTINUOUS WORKSTATION EVALUATION AND IN-SPACE WORKLOAD MEASUREMENTS

*Quotes from the 1985 Williamsburg, Virginia, RT&E Workshop*

**AUTOMATION AND ROBOTICS**

**ACCOMMODATION ISSUES**

- o "ROBOT FRIENDLY" INTERFACES FOR SERVICING, ASSEMBLY, AND DOCKING
- o STANDARD UTILITIES REQUIRED FROM MOBILITY SYSTEMS (RMS, MRMS, OMV, OTV, ETC.)
- o SAFETY
- o COMPUTING POWER, DATA STORAGE, SYSTEM ARCHITECTURES
- o STANDARDS FOR END EFFECTORS, ARMS, HOLDERS, ETC.
- o MASS/VOLUME MODEST
- o ASTRONAUT TRAINING REQUIRED
- o FORMATION FLYING REQUIRED
- o EVA NECESSARY IN SOME CASES
- o IVA ACTIVITY REQUIRED
- o HIGH BANDWIDTH VIDEO/ENCRYPTION COMMUNICATIONS SYSTEM

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

Background and Objectives

***Subthemes: Robotics, Teleoperation, and Artificial Intelligence; Summary of Williamsburg Workshop ('85)***

**Antal K. Bejczy**  
Jet Propulsion Laboratory

**RECOMMENDATIONS**

- o ACCELERATE EXPERIMENT SCHEDULE - IMPACT SPACE STATION
- o ACTIVE FOLLOW-UP TO EMBED TECHNOLOGY ACCOMMODATION ISSUES WITH SPACE STATION
- o ESTABLISHMENT OF IN-SPACE TECHNOLOGY ADVOCACY COMMITTEE
- o WORK WITH ULTIMATE USER GROUPS
- o ENCOURAGE USERS TO COME FORWARD
- o EXPLORE CREATIVE WAYS OF COST SHARING
- o DEVELOP AND DISSEMINATE SPACE STATION IN-SPACE RESEARCH CAPABILITY
- o BROADEN RESEARCH USER LIAISON WITH STATION
- o COORDINATE BETWEEN PANELS - DISTRIBUTE TO PARTICIPANTS
- o ESTABLISH CONTINUING MAIL LIST AND FOCAL POINTS

===== *Quotes from the 1985 Williamsburg, Virginia, RT&E Workshop* =====

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.1 Robotic Systems

*Robotics*

Al Meintel

NASA Langley Research Center

**INTRODUCTION/BACKGROUND**

- **AUTOMATIC MACHINE  
SPECIAL PURPOSE MECHANISM**
- **REPROGRAMMABLE MULTIFUNCTIONAL MACHINE  
INDUSTRIAL ROBOT**
- **ADAPTIVE ROBOT  
SENSOR BASED**
- **TELEROBOT  
SUPERVISED MACHINE**
- **INTELLIGENT ROBOT  
GOAL DRIVEN**

**MISSION APPLICATIONS**

- **ASSEMBLY**
- **INSPECTION**
- **SERVICING**
- **EXPERIMENTATION**
- **MANUFACTURING**
- **REPAIR**
- **CONSTRUCTION**
- **EXPLORATION**

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.1 Robotic Systems

*Robotics*

Al Meintel

NASA Langley Research Center

**TECHNOLOGY NEEDS**

- MECHANISMS
- SENSORS
- CONTROL
- PLANNING
- FAULT TOLERANCE
- SYSTEMS ARCHITECTURE

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- MECHANISMS
  - REDUNDANT MANIPULATORS WITH LOW WEIGHT & POWER
  - POSITIVE RETENTION OF END EFFECTORS/TOOLS
  - MOBILITY
- SENSORS
  - END POINT DETERMINATION
  - COLLISION DETECTION
  - DATA CORRELATION
- CONTROLS
  - FLEXIBILITY
  - DISTURBANCE COMPENSATION
  - DYNAMIC INTERACTION
- OPERATOR INTERFACE
  - DYNAMIC SIMULATION
  - MONITORING
  - INTERACTIVE REPLANNING

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.1 Robotic Systems

*Robotics*

Al Meintel  
NASA Langley Research Center

**SUMMARY/RECOMMENDATIONS**

- IN-SPACE EXPERIMENTS
  - FLEXIBILITY
  - DYNAMIC INTERACTIONS
  - FLIGHT QUALIFIED HARDWARE
  - MECHANISMS
  - SENSORS
  - COMPUTERS
  - SYSTEM VALIDATION
- STANDARDIZATION
- EFFICIENT ROBOTIC PROGRAMMING
- FAULT TOLERANCE/REDUNDANCY
- TELEROBOTICS

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.1 Robotic Systems**

#### ***Robotics***

**T.M. Depkovich and J.R. Spofford**  
Martin Marietta Corporation, Space Systems Company

## **INTRODUCTION/BACKGROUND**

- R&D ACTIVITIES HAVE DEVELOPED AN ARRAY OF TECHNIQUES FOR ROBOTIC SYSTEM CONTROL
- MATURE AND NEAR MATURE AREAS INCLUDE.
  - POSITION CONTROL
  - COMPLIANT CONTROL
  - COORDINATED DUAL ARM CONTROL
- FEASIBILITY DEMONSTRATIONS HAVE INCREASED CONFIDENCE IN TECHNOLOGY
- MISSION APPLICATION ASSESSMENT SUFFERS FROM "CHICKEN AND EGG" SYNDROME
  - MISSIONS UNWILLING TO COMMIT WITHOUT FIRM DEFINITION OF ROBOTIC CAPABILITY
  - ROBOTIC CAPABILITY ONLY GENERALLY DEFINED BECAUSE OF LACK OF MISSION SUPPORTEXAMPLE: "DESIGN FOR SERVICING"
- BROAD RANGE OF POTENTIAL APPLICATIONS
  - EVA: CONSTRUCTION, INSPECTION, REFURBISHMENT, REPAIR, CONTINGENCY
  - IVA: HOUSEKEEPING, EXPERIMENTS

## **TECHNOLOGY NEEDS**

- DEMONSTRATIONS PERFORMED OVER THE PAST SEVERAL YEARS HAVE SHOWN FEASIBILITY OF ALL MAJOR TECHNOLOGY ELEMENTS NECESSARY FOR ROBOTIC SERVICING PROGRAM
- MAJOR SHORTFALL AT THIS TIME IS A LACK OF CONSENSUS ON MEANS OF SPECIFYING MANIPULATOR SYSTEM PERFORMANCE REQUIREMENTS AND VALIDATING SYSTEM PERFORMANCE
- VIRTUALLY ALL CURRENT SPECIFICATIONS ARE STATIC; TO BE MEANINGFUL AND USEFUL, DYNAMIC SPECIFICATIONS ARE ALSO REQUIRED
- SOLUTION IS ACHIEVED THROUGH THE UNDERSTANDING OF RELATIONSHIP BETWEEN TASK FUNCTIONAL DESCRIPTION AND MANIPULATOR CLOSED-LOOP DYNAMIC IMPEDANCE
- EQUIVALENT TO ASSIGNING UNITS ON DEXTERITY
- THREE POTENTIAL APPROACHES TO ESTABLISHING THESE RELATIONSHIPS
  - ANALYTICAL (NOT LIKELY)
  - SIMULATION (LIKELY WITH ADVANCED CAD/CAE)
  - EMPIRICAL (BEST NEAR TERM SOLUTION)

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## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.1 Robotic Systems**

#### ***Robotics***

**T.M. Depkovich and J.R. Spofford**  
Martin Marietta Corporation, Space Systems Company

## **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- MAJORITY OF SPACE ISSUES CAN BE ANSWERED THROUGH GROUND BASED TESTING AND EXPERIMENTATION
- SPACE BASED EXPERIMENTS SHOULD BE VIEWED AS FINAL LINK IN CHAIN OF VALIDATION STUDIES NECESSARY PRIOR TO HANDOVER TO OPERATIONAL COMMUNITY
- DEDICATED EXPERIMENTAL TESTBED AVAILABLE TO RESEARCH COMMUNITY FOR GENERAL INVESTIGATIONS
  - MECHANISMS
  - SENSORS
  - CONTROL
  - PROCESSING
  - MMI
- KEY INITIAL EXPERIMENTS
  - CONTROL LAW VALIDATION
    - COMPLIANT CONTROL
    - CONTROL WITH LARGE PAYLOADS
    - COORDINATION
    - SUPERVISORY CONTROL
  - PERFORMANCE DATABASE FOR OPERATIONS ASSESSMENT

## **SUMMARY/RECOMMENDATIONS**

- ROBOTIC TECHNOLOGY NOW READY TO ADVANCE TO MATURE TECHNOLOGY STATUS
- THIS REQUIRES THE ABILITY TO UNAMBIGUOUSLY SPECIFY PERFORMANCE REQUIREMENTS; BOTH STATIC AND DYNAMIC
- THIS ABILITY ESSENTIAL TO DESIGN AND VALIDATION PROCESS; AN IMPORTANT FACTOR IN ACHIEVING COST EFFICIENCY
- CAPABILITY NOW EXISTS FOR EMPIRICAL DETERMINATION OF DYNAMIC REQUIREMENTS
- EXPERIMENTAL TESTBED REQUIRED TO SUPPORT ADVANCED RESEARCH
- KEY TO TESTBED SUCCESS IS FLEXIBILITY IN ACCEPTING NEW TECHNOLOGY
  - MECHANISMS
  - SENSORS
  - PROCESSING
  - ALGORITHMS
  - MMI
- LAST STEP IS FINAL VALIDATION OF TECHNOLOGY

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## AUTOMATION AND ROBOTICS

Theme 5 of 8

### 5.1 Robotic Systems

#### *Robots in Space*

Prof. Delbert Tesar  
University of Texas at Austin

## INTRODUCTION/BACKGROUND TECH BASE ISSUES FOR ROBOTICS

- I. LIGHTWEIGHT
  1. ROBOTS ARE LIMBER
  2. MUST BE MADE ELECTRONICALLY RIGID
  3. REQUIRES COMPLETE PARAMETRIC MODEL
  4. LEVEL OF CONTROL FAR BEYOND PRESENT CAPABILITY
- II. PRECISION UNDER DISTURBANCE
  1. PRECISION LIGHT MACHINING
  2. REAL TIME DYNAMIC MODEL
  3. ADAPTIVE CONTROL
  4. FEEDFORWARD COMPENSATION
- III. MAN MACHINE INTERFACE
  1. NEED INCREASES WITH BETTER TECHNOLOGY
  2. SHOULD BE KINESTHETIC (ANALOG)
  3. FORCE FEEDBACK ESSENTIAL
  4. GENERIC UNIVERSAL MANUAL CONTROLLER
- IV. DYNAMICS OF DOCKING
  1. SHOCK TO STATION UNDESIRABLE
  2. SATELLITE SPIN AND WOBBLE IS COMPLEX
  3. PRESENTLY REQUIRES 8 TO 10 hours
  4. SOPHISTICATED MANIPULATOR DYNAMICS REQUIRED
- V. LEVEL OF TECHNOLOGY REQUIRED
  1. FAR BEYOND TODAY'S INDUSTRIAL ROBOT
  2. GEOMETRY MUST BE MORE GENERIC (PARALLEL)
  3. DYNAMIC CONTROL TECHNOLOGY GROSSLY INADEQUATE
  4. BALANCE OF ELECTRICAL AND MECHANICAL ESSENTIAL

## GENERIC TECHNOLOGY NEEDS/VOIDS

<u>NEEDS</u>	<u>REMARKS</u>
1. <u>MULTI-TASK</u> CAPABILITY	<u>NUMBER</u> OF DIFFERENT PHYSICAL <u>TASKS</u> FEASIBLE
2. LEVEL OF <u>MACHINE</u> <u>INTELLIGENCE</u>	<u>LEVEL OF INTEGRATION</u> OF COMPUTER HARDWARE, SOFTWARE, ARTIFICIAL INTELLIGENCE, ETC.
3. <u>TIME EFFICIENT</u> OPERATION	<u>SPEED OF PERFORMANCE</u> RELATIVE TO HUMAN ACTING ALONE
4. UNSTRUCTURED TASK LEVEL	LEVEL OF <u>NUMERICAL UNCERTAINTY</u> IN TASK SPECIFICATION
5. <u>GEOMETRICAL</u> <u>DEXTERITY</u>	EFFECTIVE <u>MOTION RANGE</u> (LINEAR AND ANGULAR) OF THE END-EFFECTOR
6. <u>PORTABILITY</u> AND MOBILITY	ABSOLUTE MOVEMENT OF <u>SHOULDER BASE</u> WITH WITH OR WITHOUT HUMAN ASSISTANCE
7. <u>PRECISION</u>	<u>ABSOLUTE PREC</u> <u>IN</u> OF POSITIONING OF <u>END-</u> <u>EFFECTOR IN 1</u> <u>D COORDINATES</u>

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.1 Robotic Systems**

#### ***Robots in Space***

**Prof. Delbert Tesar**  
University of Texas at Austin

## **SPECIFIC TECHNOLOGY NEEDS/VOIDS REAL-TIME SYSTEM MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL**

### NEEDED DEVELOPMENT

- DEMONSTRATE MODEL REFERENCE CONTROL
  - RIGID LINK MODEL
  - COMPENSATE FOR APPLIED LOADS
  - COMPENSATE FOR INERTIA LOADS
- EXPAND TO INCLUDE DEFLECTIONS
  - LINK FLEXIBILITY
  - ACTUATOR FLEXIBILITY
- ESTABLISH OPERATIONAL SOFTWARE
- DEMONSTRATE IN ACTUAL MACHINING OPERATIONS

### TASK DESCRIPTION

- EXPAND RANGE OF APPLICATIONS
  - FOR GENERIC MANUFACTURING SYSTEMS
  - USE FEED FORWARD COMPENSATION
- ON LINE COMPUTATION
  - FULL MODELING MATRICES
  - REAL TIME (< 30 msec.)
- ARRAY PROCESSOR IMPLEMENTATION
  - PIPELINED COMPUTATION
  - RECURSION IN ALGORITHM

## **ROBOT TECHNOLOGY NEEDS FOR SPACE**

- I. ASSEMBLY OF SPACE STRUCTURES
  1. HANDLING OF LARGE MODULES
  2. PRECISE SUB-ASSEMBLY TASKS
  3. PRECISION WELDING AND FORMING
  4. PRECISION LIGHT MACHINING
- II. SPACE STATION MAINTENANCE AND REPAIR
  1. CONTINUOUS INSPECTION REQUIRED
  2. 40% OF REPAIRS TO BE UNPLANNED
  3. UNSTRUCTURED TASK ENVIRONMENT
  4. PRECISION UNDER DISTURBANCE
- III. SATELLITE SERVICING AND REPAIR
  1. 75 MISSIONS/YEAR
  2. UNSTRUCTURED TASKS
  3. SOME PRECISION WORK UNDER DISTURBANCE
  4. DOCKING DYNAMICS CRITICAL
- IV. HAZARDOUS MANUFACTURING AND LABORATORY EXPERIMENTS
  1. CLUTTERED ENVIRONMENT IN MODULE
  2. CLEAN ROOM ATMOSPHERE
  3. ABSOLUTE STABILITY DESIRED
  4. FURNACE RENOVATION CRITICAL
- V. MAINTENANCE OF ROBOTS
  1. SOFTWARE ADAPTABILITY TO CHANGE IN PARAMETERS
  2. MODULARITY FOR MAINTAINABILITY
  3. MODULE REPLACEMENT FOR TECHNOLOGY UP DATE
  4. DUALITY IN CRITICAL MAINTENANCE OPERATIONS

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**AUTOMATION AND ROBOTICS**

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5.1 Robotic Systems

*Robots in Space*

Prof. Delbert Tesar  
University of Texas at Austin

**IMMEDIATE RESEARCH NEEDS  
FOR  
SPACE STATION ROBOTICS**

- ARCHITECTURE OF ROBOTICS SYSTEMS
- UNIVERSAL MAN-MACHINE INTERFACE FOR ROBOTIC MANIPULATOR SYSTEMS
- CONTROL OF MULTIPLE ARM ROBOTIC SYSTEMS
- ROBUST CONTROL OF FLEXIBLE "CHERRY PICKER" ROBOTIC MANIPULATOR
- REALTIME SYSTEM MODELING FOR MODEL REFERENCE ADAPTIVE CONTROL
- METROLOGY FOR ROBOTIC SYSTEMS

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## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.2 Teleoperations**

#### ***Space Operations, Now and Future***

**Charles R. Price**

NASA Johnson Space Center, Teleoperation Systems Branch

## **INTRODUCTION/BACKGROUND**

- THE SPACE SHUTTLE DEPLOYMENT AND RETRIEVAL SYSTEM IS THE STATE OF THE ART FOR IN-SPACE TELEOPERATIONS
- THE PDRS CONSISTS OF THE REMOTE MANIPULATOR SYSTEM AND ITS ANCILLARY EQUIPMENT MOUNTED ON THE SPACE SHUTTLE ORBITER
- THE PDRS FUNCTIONALITIES ARE:
  - GRAPPLE, TRANSPORT, ORIENTATION, AND RELEASE OF A PAYLOAD
  - TRACK, CAPTURE, GRAPPLE, TRANSPORT, ORIENTATION, AND BERTHING OF A SATELLITE
  - EVA CREW TRANSPORT, POSITIONING, ORIENTATION VIA GRAPPLED MOBILE FOOT RESTRAINT
  - LOCAL ILLUMINATION VIA RMS-MOUNTED LIGHTS
  - DIRECTIONAL, AUGMENTED VIEWING VIA RMS-MOUNTED CCTV
  - FREESTREAM EXPERIMENT SENSOR POSITIONING
  - POWER AND DATA INTERFACE SERVICES FOR PAYLOADS
  - RESOURCE FOR CREATIVE SOLUTIONS TO UNPLANNED PROBLEMS

## **NEAR TERM FUTURE TELEOPERATOR APPLICATIONS**

- ON-ORBIT:
  - ORBITER-BASED SPACE STATION ASSEMBLY
  - SPACE STATION-BASED SPACE STATION ASSEMBLY
  - SATELLITE SERVICING
- TERRESTRIAL SPACE APPLICATIONS:
  - KSC TURN-AROUND OPERATIONAL COST REDUCTION APPLICATION, e.g.:
    - TILE INSPECTION
    - PAYLOAD BAY INSPECTION
  - NSTS TURNAROUND COSTS ARE \$250 MILLION/FLIGHT
  - SUCCESSFUL GROUND APPLICATIONS ENHANCE ON-ORBIT APPLICATIONS

### **LONGER TERM TELEOPERATOR APPLICATIONS (WITH TRENDS TOWARDS TELEROBOTICS)**

- EXPANDED ON-ORBIT SERVICING OF SATELLITES
- EXPANDED SHUTTLE TURNAROUND OPERATIONAL SUPPORT
- ON-ORBIT MAINTENANCE OF SPACE STATION
- ON-ORBIT SERVICING OF PLATFORMS, INCLUDING HARVESTING OF PRODUCTS
- ON-ORBIT ASSEMBLY OF LUNAR AND DEEP SPACE EXPLORATORY VEHICLES
- REMOTE LUNAR MINING OPERATIONS

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## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.2 Teleoperations**

#### ***Space Operations, Now and Future***

**Charles R. Price**

NASA Johnson Space Center, Teleoperation Systems Branch

### **TECHNOLOGY NEEDS FOR SPACE SHUTTLE PAYLOAD DEPLOYMENT AND RETRIEVAL SYSTEM SUPPORT TO SPACE STATION ASSEMBLY**

- **FORCE/TORQUE FEEDBACK**
- **CONSTRAINED MOTION CONTROL FUNCTIONALITY**
  - RATE COMMAND TO CONTACT TRANSITION
  - RATE COMMAND WITH VARIABLE RESISTANCE LOADING
  - SPLIT AXIS MIXED MODES
- **LOW SCAR GRAPPLE FIXTURE**
- **DISPLAY OF COMPLEX ASSEMBLY WORKSPACES TO CREW**
- **PRACTICAL COLLISION AVOIDANCE (INFERS LIMITED MACHINE VISION)**
- **SINGLE WORKSTATION CONTROL OF MULTIPLE, HIERARCHIAL (AND SOME PARALLEL) MANIPULATORS**
- **FAULT TOLERANCE BY DESIGN TO IMPROVE MISSION SUCCESS PROBABILITIES**

### **PERCEIVED VOIDS IN THE IN-SPACE EXPERIMENTS REGARDING TELEOPERATORS**

- **ON-ORBIT:**
  - DISPLAY OF COMPLEX (ASSEMBLY) WORKSPACE UNDER ORBITAL LIGHTING CONDITIONS TO CREW
  - COLLISION AVOIDANCE SENSING, CALCULATION, AND DISPLAY TO CREW
  - SINGLE WORKSTATION CONTROL OF
    - HIERARCHIAL SETS OF MANIPULATORS
    - PARALLEL SETS OF MANIPULATORS
    - TOTAL DEGREES OF FREEDOM EXCEEDING FIFTY OR MORE
  - DEMONSTRATION/VERIFICATION OF MATH MODELED CONSTRAINED MOTION AND CONTACT DYNAMICS
  - FAILURE DETECTION, ISOLATION, AND AUTOMATIC RECONFIGURATION OF A TELEOPERATOR SYSTEM
  - DISTRIBUTED, JOINT-LEVEL REPROGRAMMABLE MICROPROCESSING FOR AN OPERATIONALLY ADAPTIVE TELEOPERATOR
- **TERRESTRIAL RELATED:**
  - FEEDFORWARD CONTROL FOR GROUND COMMAND OF ON-ORBIT TELEOPERATOR
  - SHUTTLE TURNAROUND COST SAVINGS APPLICATIONS

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**AUTOMATION AND ROBOTICS**

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5.2 Teleoperations

***Space Operations, Now and Future***

**Charles R. Price**

NASA Johnson Space Center, Teleoperation Systems Branch

**SUMMARY/RECOMMENDATIONS**

- ASSEMBLY OF COMPLEX WORKPIECES IS THE MAJOR NEAR TERM TECHNOLOGY DRIVER FOR IN-SPACE TELEOPERATORS
- IN-FLIGHT EXPERIMENTS SUPPORTING ASSEMBLY WILL ALSO APPLY TO SATELLITE SERVICING TELEOPERATION
- RECOMMEND MORE EMPHASIS BE PLACED ON PRACTICAL COLLISION AVOIDANCE AND DISPLAY OF COMPLEX WORKSPACE TO CREW

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## **AUTOMATION AND ROBOTICS**

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### **5.2 Teleoperations**

#### ***Teleoperation***

**Paul B. Pierson**  
General Electric Aerospace

## **INTRODUCTION/BACKGROUND**

- **SPACE TELEOPERATION**
  - CANDIDATE MISSIONS DEFINED
  - COST EFFECTIVENESS UNDER REVIEW
  - TELEOPERATION IS POTENTIALLY A VIABLE OPTION
- **TECHNOLOGY BASE**
  - INDUSTRIAL ROBOTICS
  - UNDERSEA, NUCLEAR POWER PLANT TELEOPERATIONS
- **SPACE TELEOPERATION/SUPERVISORY CONTROL**
  - COMBINATION OF ROBOTICS AND TELEOPERATIONS
  - COMPLEX OPERATOR INTERFACE
  - HIERARCHICAL CONTROL/INFORMATION ARCHITECTURE
  - COMMUNICATION TIME DELAYS
  - MUST PERFORM PLANNED/UNPLANNED TASKS
  - SPACE CONDITIONS

### **CAPABILITIES REQUIRED FOR MISSION APPLICATION TASKS**

- **CAMERA/INSTRUMENT POSITIONING FOR INSPECTION**
- **HEAVY/LIGHT OBJECT MANIPULATION AND POSITIONING**
- **MANIPULATION IN FREE SPACE AND WITH CONTACT CONSTRAINED MOTIONS**
- **APPLICATION OF FORCE**

## **MISSION APPLICATIONS**

- **INSPECTION (ROUTINE OR DIAGNOSTIC)**
- **ORU/PAYLOAD EXCHANGE (PAYLOAD UPGRADE, EXPERIMENT REPLACEMENT)**
- **REFURBISHMENT/REPLENISHMENT OF EXPENDABLES (FUELS, CRYOGENS)**
- **ASSEMBLY OF LARGE SPACE STRUCTURES, COMPONENTS**
  - SPACE STATION TRUSSES AND UTILITY TRAYS
  - LARGE ANTENNAS, NUCLEAR POWERED PLATFORMS
- **COMPONENT REPLACEMENT**
  - CONTAMINATED OR WORN PARTS
- **INSTRUMENT ADJUSTMENT, CALIBRATION**
  - SPACE TELESCOPE, EARTH OBSERVATION SYSTEM
- **REPAIR/CONTINGENCY OPERATIONS (SOLAR MAX)**
- **TELESCIENCE**
- **MANUFACTURING**

### **MISSION PLATFORMS**

- **SPACE STATION**
  - MASSIVE PLATFORM BASE
  - EVA BACKUP: CONTINGENCY EVENTS, SERVICE THE SERVICER
- **UNMANNED PLATFORM (e.g., POLAR, GEO)**
  - LOW MASS PLATFORM: CONTROL DYNAMICS ISSUES, INTERACTION WITH OTHER FLEXIBLE STRUCTURES
  - LONG PERIODS OF INACTIVITY
  - NO EVA BACKUP

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## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.2 Teleoperations**

#### ***Teleoperation***

**Paul B. Pierson**  
General Electric Aerospace

## **OPERATOR INTERFACE TECHNOLOGY NEEDS**

- INTELLIGENT DISPLAYS
  - EYES/HANDS BUSY OPERATION
  - MUST (ONLY) PROVIDE CRITICAL INFORMATION
- VISUAL PERCEPTION SYSTEMS
  - POSITION
  - FORCE
- HAND CONTROLLERS
  - POSITION/RATE CONTROL
  - FORCE REFLECTION OPTION
- SPEECH RECOGNITION/SYNTHESIS
  - STRESS
  - ENVIRONMENT

## **CONTROL SYSTEM TECHNOLOGY NEEDS**

- STABILITY GIVEN WIDE RANGE OF MANIPULATION SPEEDS, OBJECT MASSES
- CONTROL PARAMETERS VARY WITH TASK/ENVIRONMENT
  - GAIN VALUES FOR POSITION/RATE CONTROL
  - PID GAINS FOR CLOSED LOOP FORCE CONTROL
  - FORCE LIMITS
- COMMUNICATION TIME DELAYS
  - WITHIN ON BOARD CONTROL ARCHITECTURE
  - ROUND TRIP TO REMOTE OPERATOR
  - IMPACTS SPEED OF MANIPULATION, FORCE CONTROL SENSITIVITY, VIABILITY
- SIMULATION
  - GROUND HARDWARE LIMITED BY 1-G
  - SYSTEM NON LINEARITIES DIFFICULT TO MODEL
  - VALIDITY OF EMPIRICALLY DERIVED PARAMETERS

## **TECHNOLOGY NEEDED IN HIERARCHICAL CONTROL/INFORMATION ARCHITECTURES**

- MERGE MANUAL/PROGRAMMED TASKS
  - TASK SCRIPT AUTHORING TOOLS
- ENABLE GROWTH TOWARD INCREASING AUTONOMY
  - PLANNING/REPLANNING GIVEN INTERVENING HUMAN ACTIONS
- IMPLEMENTATION IN FLIGHT QUALIFIED PROCESSORS
  - CONSTRAINTS IMPOSED BY PLATFORM DATA COMMUNICATIONS
- SUPERVISORY COMMAND LANGUAGE

## **PROBLEMS ASSOCIATED WITH HUMAN CONTROL OF SPACE MANIPULATORS**

- LIMITED WORKSPACE VIEWS
  - CAMERA POSITIONS FOR OBJECT GRASPING, HIDDEN SURFACES
  - NEED STEREO OR MULTIPLE VIEWS FOR UNSTRUCTURED TASKS
- HUMAN INTERACTION WITH PLATFORM CONTROL DYNAMICS DURING TELEOPERATION
- AVOIDANCE OF MANIPULATOR SINGULARITIES
  - DURING MANUAL CONTROL
  - STARTING PROGRAMMED TRAJECTORIES AFTER MANUAL POSITIONING
- COLLISION AVOIDANCE
  - ROBOT VERSUS WORKSPACE
  - CARRIED OBJECT VERSUS WORKSPACE
- REHEARSAL
  - GROUND AND IN-FLIGHT
  - CONTROL DYNAMICS
  - MANIPULATOR STIFFNESS, STRENGTH
  - TIME BETWEEN REHEARSAL AND ACTION
- MANY CONTROL PARAMETERS NEED TO BE SET WHEN UNPLANNED TASKS ARE TO BE PERFORMED

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## **AUTOMATION AND ROBOTICS**

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### **5.2 Teleoperations**

#### ***Teleoperation***

**Paul B. Pierson**  
General Electric Aerospace

### **IN-SPACE EXPERIMENTATION NEEDS/VOIDS, MAN-MACHINE INTERFACE**

- TELEOPERATION WITH OPERATOR IN MICROGRAVITY
  - FORCES EXPERIENCED WITH HAND CONTROLLERS
  - IMPACT ON VOICE ACOUSTICS FOR SPEECH RECOGNITION
- TELEOPERATION WITH OPERATOR ON GROUND
  - LIMITED COMMUNICATION BANDWIDTHS
  - TIME DELAYS
- CAMERA SYSTEM CONTROL/ADEQUACY
  - SELECTION, POSITIONING, POINTING, ZOOM, FOCUS, IRIS
  - LIGHTING GIVEN DYNAMIC SOLAR ILLUMINATION CONDITIONS
  - COMMUNICATION BANDWIDTH
- MANUAL SELECTION OF CONTROL PARAMETERS FOR UNPLANNED TASKS
- DYNAMIC INTERACTION BETWEEN PLATFORM, TELEROBOT/OBJECT, OPERATOR
- ACCURACY, STABILITY OF LIGHT MANIPULATOR  
GIVEN WIDE RANGE OF OBJECT MASSES
- ACCURACY OF COMPUTER SIMULATION DYNAMIC MODEL
- VALIDITY/ACCURACY OF CONTROL PARAMETERS  
DERIVED/DEMONSTRATED ON GROUND SIMULATION  
HOW TO TEST PRIOR TO EXECUTING SINGULAR EVENT

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## AUTOMATION AND ROBOTICS

Theme 5 of 8

### 5.2 Teleoperations

#### *Multimode Operator Interfaces, Intelligent Displays, Hierarchical-Control Communication Time Delay Visual Perception Systems*

Thomas B. Sheridan

Massachusetts Institute of Technology, Man-Machine Systems Laboratory

#### BACKGROUND

- Solid man-in-space successes in Mercury, Gemini, Apollo. Solid automation demonstrations in deep space, shuttle RMS. Some questions about need for man-in-space in the future, possibilities for remote control.
- Forty years of teleoperator experiments and operations. in nuclear plants, undersea, construction, and space.
- Steadily evolving capability of teleoperation and telerobotics. (Reality has lagged public and in some cases R&D rhetoric, but nevertheless is overtaking NASA's actual preparedness.)
- NASA tradition of attention to empirical human factors, but spotty development of human factors discipline outside.
- Fallacious tendency of Congress and US public to see human participation in space and automation/robotics as mutually exclusive. (They should be seen as symbiotic.)
- Legitimate conservatism re human life, resultant demand for reliable non-expendable hardware have inhibited progress where hardware could be expendable without endangering life.
- Growing competition from Europe and Japan in space technology.
- Current interest in commercial space vehicles.

#### TECHNOLOGY NEEDS IN TELEOPERATION AND TELEROBOTICS

- Flexible, human friendly supervisory command languages which mix analogic and symbolic elements, and enhance computer understanding.
- means to control redundant degree-of-freedom kinematics (arms of  $\geq 7$  DOF, arms plus vehicles plus hands).
- Operator adjustable Impedance between master and arm, slave and task.
- Video aids to enhance depth: stereo and other.
- Predictor instruments and other means to accommodate time delay in both video and force, and predict contact.
- Manipulator arms which are lighter, stiffer (adjustable), and of higher bandwidth and control precision.
- Smart end effectors having more dexterity (more degrees of freedom).
- Higher resolution and more robust touch and proximity sensors.
- Touch display to hands, eyes, ears or other parts of body.

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**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.2 Teleoperations

***Multimode Operator Interfaces, Intelligent Displays, Hierarchical-Control  
Communication Time Delay Visual Perception Systems***

**Thomas B. Sheridan**

Massachusetts Institute of Technology, Man-Machine Systems Laboratory

**TECHNOLOGY NEEDS IN TELEROBOT DESIGN,  
MISSION PLANNING AND MONITORING**

- Theory of telepresence, what it is and what it contributes.
- Theory and experimental measures of manual dexterity.
- Techniques for control of unpredictable dynamics.
- Computer understanding of operator queries and stated intentions (for expert systems and telerobot control aids).
- Real time simulation and associated graphics for on-line multiobjective control decisions and planning.
- Computer-based aids for telerobot failure detection, diagnosis and recovery.
- Theory of allocating, trading and sharing of telerobot control functions between human and computer.
- Techniques for simulating large-scale space teleoperation / telerobotics operations on the ground.

**PROPOSED EXPERIMENTS IN SPACE**

- Demonstrations of teleoperator (direct) and telerobot (supervisory) control in dynamic tasks, e.g., throwing and catching objects, rendezvousing with tumbling satellite and inspecting or inserting/removing module.
  - with and without force feedback.
  - with 6 and redundant degrees-of-freedom.
    - one arm-hand
    - two arm-hands
    - vehicle plus arm-hand simultaneously.
  - controlled from the ground.
  - using touch when vision is obscured.
- Demonstration of predictor instruments to accommodate time-delayed video and force feedback.
- Demonstrations of telepresence.
- Demonstrations of telescience by scientists on ground.
- Demonstration of failure recovery drills by various human and machine combinations.

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## **AUTOMATION AND ROBOTICS**

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### **5.3 Artificial Intelligence**

#### ***In-Space Experiments in Artificial Intelligence***

**Dr. Peter Friedland / Nancy Sliwa**  
NASA Ames Research Center / NASA Langley Research Center

## **INTRODUCTION/BACKGROUND**

- NASA R&D PROGRAMS
  - SYSTEMS AUTONOMY TECHNOLOGY PROGRAM (CSTI)
  - SPACE STATION FREEDOM ADVANCED TECHNOLOGY PROGRAM
  - PATHFINDER
- CURRENT CAPABILITIES:
  - INCO EXPERT SYSTEM IN MISSION CONTROL
  - \*HST SCHEDULER IN END TO END TESTING, SHARP, AUTOCLASS
- ARTIFICIAL INTELLIGENCE (AI) ELEMENTS
  - REASONING UNDER UNCERTAINTY
  - LEARNING
  - CAUSAL MODELLING
  - KNOWLEDGE ACQUISITION
  - ADVANCED PLANNING METHODS
  - COOPERATING KNOWLEDGE BASE SYSTEMS
  - VALIDATION TECHNOLOGIES
- DIFFERENCES BETWEEN GROUND VS. SPACE-BASE AI SYSTEMS
  - AVAILABILITY OF SUFFICIENT PROCESSING POWER AND MEMORY
  - REALTIME CONSTRAINTS
  - RELIABILITY CONSTRAINTS
  - ENVIRONMENTAL UNCERTAINTY
  - PERCEIVED VS. REAL RISK

## **TECHNOLOGY NEEDS**

- BUILDING AND USING VERY LARGE KNOWLEDGE BASES
  - AUTOMATIC KNOWLEDGE ACQUISITION
  - EFFECTIVE KNOWLEDGE COMBINATION FROM MANY SOURCES
  - REPRESENTATION AND OPERATIONALIZATION OF MASSIVE AMOUNTS OF KNOWLEDGE
- COLLABORATION
  - DISTRIBUTED PROBLEM SOLVING
  - MULTIPLE AGENTS
  - GRACEFUL INTERACTION WITH HUMANS
- CAUSAL REASONING
- UNCERTAINTY MANAGEMENT
  - REASONING ABOUT UNCERTAINTY
  - REACTIVE REPLANNING TO COPE WITH UNCERTAINTY
- VALIDATION AND VERIFICATION OF INTELLIGENT SYSTEMS

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.3 Artificial Intelligence**

#### ***In-Space Experiments in Artificial Intelligence***

**Dr. Peter Friedland / Nancy Sliwa**  
NASA Ames Research Center / NASA Langley Research Center

## **TECHNOLOGY NEEDS**

- **PLANNING/SCHEDULING IN REAL, COMPLEX SITUATIONS**
- **DESIGN**
  - **STATIC GROUND-BASED DESIGN**
  - **DYNAMIC FLIGHT-BASED REDESIGN**
- **MACHINE LEARNING**
  - **DISCOVERY**
  - **IMPROVEMENT OF PERFORMANCE WITH EXPERIENCE**
  - **ACQUIRING EXPERTISE**
- **SPACEBORNE SYMBOLIC PROCESSORS**

## **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- **FLIGHT TEST NEEDED FOR INTEGRATED HARDWARE/SOFTWARE SYSTEMS, e.g., PROCESSOR LIMITATIONS, ROBOTICS SYSTEMS**
- **IN GENERAL, AI SOFTWARE SHOULD BE TREATED LIKE ANY OTHER COMPUTER CODE – GROUND SIMULATION SHOULD BE SUFFICIENT FOR VALIDATION. BUT VALIDATION AND VERIFICATION OF AI SOFTWARE IS STILL A RESEARCH ISSUE**
  - NEW TECHNIQUES MAY REQUIRE FLIGHT EXPERIMENTATION**
  - **PERCEIVED RISK MAY ADVISE FLIGHT EXPERIMENTATION**

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.3 Artificial Intelligence

***In-Space Experiments in Artificial Intelligence***

Dr. Peter Friedland / Nancy Sliwa  
NASA Ames Research Center / NASA Langley Research Center

**SUMMARY**

- AI TECHNOLOGY WILL BE CRITICAL TO FUTURE SPACE MISSIONS FOR BOTH GROUND AND FLIGHT USE
- INTEGRATED HARDWARE/SOFTWARE FLIGHT TESTS WILL BE NECESSARY
- IN GENERAL, GROUND-BASED VALIDATION IS SUFFICIENT FOR SOFTWARE
- SOME FLIGHT VALIDATION MAY BE NECESSARY TO ESTABLISH A "TRACK RECORD" FOR AI SOFTWARE

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.3 Artificial Intelligence**

#### ***Artificial Intelligence: An Industry View***

**David A. Rosenberg**  
ISX Corporation

## **INTRODUCTION/BACKGROUND**

- AI SPACE APPLICATIONS WILL CLEARLY BE HYBRIDS, INVOLVING CONVENTIONAL AND AI-BASED COMPONENTS TO SOLVE PROBLEMS THAT NEITHER COULD COPE WITH ALONE
- THESE PRODUCTS ARE GENERALLY KNOWN AS INTELLIGENT SYSTEMS. HERE, INTELLIGENCE IMPLIES THE USE OF EXPLICIT KNOWLEDGE (OFTEN META-KNOWLEDGE)
- INTELLIGENT AUTONOMOUS SYSTEMS UTILIZE EXPLICIT KNOWLEDGE OF A TARGET SYSTEM AND OF DESIRED GOALS TO EVALUATE OR CONTROL THE TARGET, WITH VARYING DEGREES OF AUTONOMY
- INTELLIGENT DECISION SUPPORT SYSTEMS EXPLOIT USER KNOWLEDGE, PLUS DOMAIN SPECIFIC KNOWLEDGE TO BETTER AID THE DECISION MAKER

## **TECHNOLOGY NEEDS**

- IN GENERAL, PAST AI-BASED SYSTEMS HAVE BEEN BRITTLE, NOT WELL INTEGRATED AS COMPONENTS OF BROADER SYSTEMS, ISOLATED FROM CRITICAL DATA OVER WHICH TO REASON, OFTEN BUILT IN AN AD HOC FASHION, AND PRECLUDED FROM REAL-TIME APPLICATIONS DUE TO SEVERE PERFORMANCE CONSTRAINTS
- TOOLS AND TECHNIQUES ARE NEEDED TO SEAMLESSLY INTEGRATE KNOWLEDGE-BASED COMPONENTS INTO A BROADER SOFTWARE SUPPORT ENVIRONMENT
- COMMON LIFE-CYCLE TOOLS AND METHODOLOGY. TECHNIQUES SUPPORTING SOFTWARE RE-USE ARE ESSENTIAL. A UNIFIED VIEW OF DATA, ESPECIALLY SHARED INFORMATION ACROSS MODULES, GEOGRAPHY, AND HARDWARE. RUN TIME SUPPORT FOR HETEROGENEOUS HARDWARE/SOFTWARE, ALONG WITH APPROPRIATE STANDARDS TO MAKE THIS FEASIBLE
- QUALIFIED AND VALIDATED HARDWARE AND SOFTWARE TO SUPPORT AI SOFTWARE COMPONENTS DO NOT EXIST
- A FIRM COMMITMENT TO INTEGRATE AI INTO REAL WORLD SYSTEMS. RISK CAN BE REDUCED WITH A PHASED, INCREMENTAL APPROACH TO COMPETENCE, BEGINNING WITH DECISION SUPPORT AND WORKING TOWARDS GREATER AUTONOMY

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.3 Artificial Intelligence

***Artificial Intelligence: An Industry View***

David A. Rosenberg  
ISX Corporation

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- IN A SENSE, AI TECHNOLOGIES ARE ORTHAGONAL TO OUR THEME AREAS, AND COULD BE APPLIED TO MOST OF THE ON-GOING EXPERIMENTS
- VALUABLE INTEGRATION EXPERIENCE COULD BE GAINED BY DEFINING, DESIGNING, BUILDING, AND FLYING AN INTELLIGENT DECISION SUPPORT SYSTEM TO AID CREW MEMBERS IN MANAGING SOME SET OF IN-SPACE EXPERIMENTS. A COMMON FRAMEWORK COULD LIKELY BE APPLIED TO SUPPORT A NUMBER OF SUCH EXPERIMENTS
- SPACE STATION FREEDOM REPRESENTS AN IDEAL OPPORTUNITY TO APPLY INTELLIGENT SYSTEMS IN BOTH CREW DECISION SUPPORT AND SEMI-AUTONOMOUS ROLES
- THE FTS PROVIDES AN OPPORTUNITY TO APPLY THE IDEAS DISCUSSED FOR HUMAN CONTROLLED AND AUTONOMOUS ROBOTICS

**SUMMARY & RECOMMENDATIONS**

- A RELATIVELY NEW CLASS OF SYSTEM, THE INTELLIGENT SYSTEM, CAN BE EFFECTIVE WHERE CONVENTIONAL OR PURE AI-BASED APPROACHES ARE NOT
- IN THE LONG RUN, INTEGRATED AI WILL BE AN ENABLING TECHNOLOGY FOR AUTONOMOUS, OR VERY COMPLEX MANNED PLANETARY MISSIONS
- IN-SPACE EXPERIMENTS COULD PROVIDE A CRUCIAL, REAL WORLD INTEGRATION OPPORTUNITY

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.3 Artificial Intelligence**

#### ***Artificial Intelligence: An Industry View***

**David A. Rosenberg**  
ISX Corporation

## **MISSION APPLICATIONS**

- SHUTTLE. WHILE NOT "DESIGNED IN" INTELLIGENT SYSTEMS COULD PLAY AN IMPORTANT ROLE
- ADAPTIVE PLANNING TECHNIQUES COULD ASSIST CREW MEMBERS IN PERFORMING NUMEROUS ACTIVITIES, SUCH AS CONDUCTING EXPERIMENTS, OR PERFORMING PAYLOAD CHECKOUT
- GREATER AUTONOMY COULD BE GIVEN TO EXPERIMENTS. KNOWLEDGE GAINED FROM THE EXPERIMENT DESIGNERS COULD REDUCE CREW MONITORING AND PROVIDE BETTER, MORE EFFICIENT CREW INTERFACE WHEN INTERVENTION IS REQUIRED
- SPACE STATION. THE SAME TECHNIQUES DESCRIBED ABOVE COULD PROVIDE EVEN MORE LEVERAGE IF WELL INTEGRATED. SIGNIFICANT IMPROVEMENTS IN OPERATIONS PLANNING, RESOURCE ALLOCATION, AND FAULT DETECTION/CORRECTION COULD BE ACHIEVED. APPLICATION TO THE UNDERLYING DISTRIBUTED COMPUTATION ENVIRONMENT IS ESPECIALLY ATTRACTIVE
- TELEROBOTICS. AUGMENTATION TO THE HUMAN INTERFACE IS ESPECIALLY ATTRACTIVE
  - ADAPTIVE PLANNING COULD BE USED TO PROVIDE HIGH LEVEL TASK PLANNING AND REPLANNING IN CONCERT WITH ACTUAL PROGRESS. THE SELECTION OF VERY LOW LEVEL FEATURES SUCH AS GRIPPING FORCE, FORCE REFLECTION RATIOS, LIGHTING CONTROL, ETC., COULD BE AUTOMATICALLY SELECTED
- AUTONOMOUS ROBOTICS. HERE, INTELLIGENT AUTONOMOUS SYSTEMS ARE AN ENABLING TECHNOLOGY
  - FOR FULLY AUTONOMOUS OPERATION, GOAL-DIRECTED, HIGH LEVEL PLANNING IS EVEN MORE IMPORTANT
  - KNOWLEDGE OF THE SYSTEM BEING SERVICED, THE SERVER ITSELF, AND OF OVERALL GOALS WILL BE REQUIRED TO PROVIDE THE HUMAN SUPPLIED FEATURES DESCRIBED ABOVE: SITUATION ASSESSMENT, MACHINE VISION, TESTING, ETC. THIS COULD BE A VERY HARD PROBLEM
  - USER DIRECTED SPECIALIZATION OF SKELETAL PLANS COULD ALSO PROVIDE A POWERFUL MECHANISM FOR DEVELOPING NEW PLANS FOR BOTH INTELLIGENT AND DUMB AUTONOMOUS ROBOTS
- PLANETARY MISSIONS. HERE, THE MUCH GREATER NEED FOR AUTONOMY MAKES AI AN "ENABLING" TECHNOLOGY. ON UNMANNED MISSIONS, KNOWLEDGE OF MISSION OBJECTIVES AND OF THE STRUCTURE AND FUNCTION OF THE SPACE VEHICLE COULD BE ESSENTIAL TO ADAPTING PLANS AND OBJECTIVES TO UNFORSEEN EVENTS

Theme 5 of 8

## AUTOMATION AND ROBOTICS

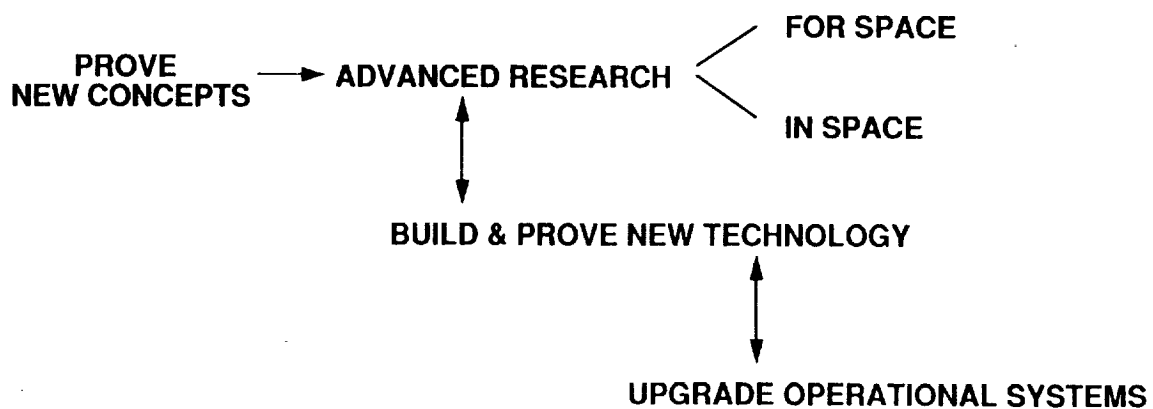
Theme 5 of 8

### 5.3 Artificial Intelligence

#### *Artificial Intelligence*

Dr. Robert Cannon  
Stanford University

## INTRODUCTION/BACKGROUND



## TECHNOLOGY NEEDS

### o USER INTERFACE

GEOMETRIC  
OBJECT-LEVEL  
SIMPLE

### o MANIPULATOR CONTROL

LIGHTWEIGHT  
FLEXIBLE  
QUICK  
PRECISE  
ROBUST  
ADAPTABLE  
GRACEFUL  
WORK FROM A MOVING BASE

Theme 5 of 8

## **AUTOMATION AND ROBOTICS**

Theme 5 of 8

### **5.3 Artificial Intelligence**

#### ***Artificial Intelligence***

**Dr. Robert Cannon**  
Stanford University

## **TECHNOLOGY NEEDS**

### **o COOPERATION**

BETWEEN MANIPULATORS  
BETWEEN ROBOTS  
BETWEEN ROBOTS AND PEOPLE

### **o NEW GENERATION OF ENGINEERS**

GOOD YOUNG ENGINEERS  
GOOD ENGINEERING PROFESSORS/PROGRAMS/SCHOOLS  
LOOK AT RADICAL IDEAS

- \* MEGASYSTEMS
- \* MICROSYSTEMS

## **IN-SPACE EXPERIMENTATION NEEDS**

- o ARTIFICIAL INTELLIGENCE NEEDS FLIGHT TESTING ONLY  
IN CONJUNCTION WITH DEPENDENT TECHNOLOGY, e.g. ROBOTICS**

- o NEED TO GET NEW GENERATION OF YOUNG ENGINEERS  
INVOLVED IN FLIGHT EXPERIMENTS**

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.3 Artificial Intelligence

***Automation and Robotics Critical Technology Requirements***

**Antal K. Bejczy**  
Jet Propulsion Laboratory

**TARGET NASA MISSIONS**

- o STS
- o GREAT OBSERVATORIES
  - HST
  - GRO
  - AXAF
  - SIRTf
- o SSFP
- o FREE FLYERS (including POP)
- o LUNAR OUTPOST
- o MARS EXPLORATION

**USER NEED TASK DRIVERS**

- o IN-SPACE ASSEMBLY
- o MATERIALS PROCESSING
- o MATERIALS HANDLING
- o SYSTEMS MAINTENANCE AND OPERATIONS
- o SATELLITE SERVICING
- o EXPLORATION

Theme 5 of 8

## AUTOMATION AND ROBOTICS

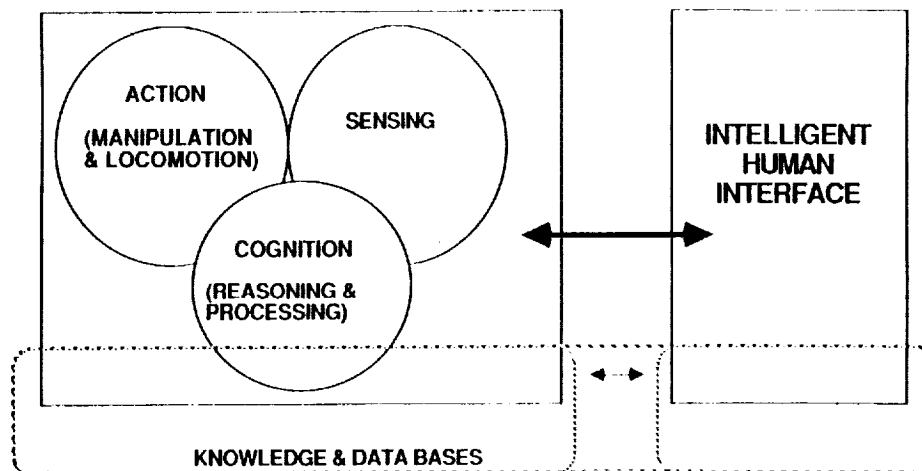
Theme 5 of 8

### 5.3 Artificial Intelligence

#### *Automation and Robotics Critical Technology Requirements*

**Antal K. Bejczy**  
Jet Propulsion Laboratory

#### INTEGRATED APPROACH FOR A & R ON A MULTI-DISCIPLINARY BASE



### GENERAL THRUST

**AUGMENT AND ENHANCE HUMAN RESOURCES/CAPABILITIES  
BY ENABLING HUMAN CONTROL OF COMPLEX SYSTEMS AT  
HIGHER & HIGHER LEVELS WHILE RETAINING CAPABILITY TO  
ENTER CONTROLLING PROCESS AT MULTIPLE LEVELS**

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

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**5.3 Artificial Intelligence**

***Automation and Robotics Critical Technology Requirements***

**Antal K. Bejczy**  
Jet Propulsion Laboratory

**SPACE ROBOTICS TASK DOMAINS**

o **WIDE RANGE OF OPERATING SCALES**

- LARGE / HEAVY (e.g. SATELLITE, PAYLOAD MANIPULATION)
- SMALL / LIGHT (e.g. INSTRUMENT ADJUSTMENT, MATERIALS PROCESSING)

o **MECHANICAL COUPLING ENVIRONMENT**

- RIGID BASE
- FLEXIBLY COUPLED
- FREE FLYING

o **VARYING ILLUMINATION ENVIRONMENT**

**SPACE ROBOTICS TECHNOLOGY NEEDS**

o **ROBUST AND SAFE MANIPULATION / LOCOMOTION**

- CONTROL LAWS
- COLLISION AVOIDANCE
- COMPLIANCE (ACTIVE OR PASSIVE)
- USE OF TASK MODELS OR ADAPTIVE CONTROL
- LOCAL AUTONOMY BASED ON SENSING
- DYNAMICS OF COUPLING TO PLATFORM

o **FAULT TOLERANT HARDWARE / SOFTWARE ARCHITECTURES**

- MECHANISMS
- ACTUATORS
- SENSORS
- SENSOR / CONTROL PROCESSORS
- FAILURE DETECTION, IDENTIFICATION, AND RECOVERY

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

**5.3 Artificial Intelligence**

***Automation and Robotics Critical Technology Requirements***

**Antal K. Bejczy**  
Jet Propulsion Laboratory

**TELEOPERATIONS, DOMAINS AND NEEDS**

o **SUPERVISORY CONTROL FOR TELEROBOTIC  
OPERATIONS IN SPACE**

- DYNAMIC TASK CONTROL
- ENHANCED VISUAL DISPLAYS WITH COMPUTATION  
(E.G. COLLISION AVOIDANCE)
- BIDIRECTIONAL M / M INTERFACES WITH  
HIERARCHICAL OBJECT-ORIENTED ARCHITECTURE  
AND MULTI-MODE CAPABILITIES
- MODELS FOR TELEROBOT AND ITS ACTIONS

o **CONTROL LOCATION**

- ON ORBIT
  - OPERATOR WITH FORCE FEEDBACK
  - ROBOT ARM - VEHICLE INTERACTION
- ON GROUND
  - COMMUNICATION DELAY / BANDWIDTH
  - INTERACTING WITH MICROGRAVITY

o **HIGH DEGREE-OF-FREEDOM SYSTEMS**

- REDUNDANT ARMS
- MULTIPLE ARMS
- DEXTROUS END EFFECTORS AND TOOLS

Theme 5 of 8

**AUTOMATION AND ROBOTICS**

Theme 5 of 8

5.3 Artificial Intelligence

***Automation and Robotics Critical Technology Requirements***

Antal K. Bejczy  
Jet Propulsion Laboratory

## **ARTIFICIAL INTELLIGENCE TASK DOMAINS**

### **◦ FAULT PROCESSING**

- AUTOMATED FAULT DETECTION, ISOLATION, RECOVERY / RECONFIGURATION
- DIAGNOSIS OF UNANTICIPATED, MULTIPLE FAULTS
- CONTINGENCY REPLANNING

### **◦ LARGE INPUT / OUTPUT SYSTEMS**

- SENSOR INTERPRETATION / FUSION
- REAL-TIME IMAGE PROCESSING
- SPEECH RECOGNITION AND SYNTHESIS

## **ARTIFICIAL INTELLIGENCE TECHNOLOGY NEEDS**

### **◦ INTEGRATED, REAL-TIME, FAULT-TOLERANT, COOPERATIVE INTELLIGENT SYSTEMS**

- PARALLEL, INTEGRATED NUMERIC / SYMBOLIC PROCESSING
- ADVANCED, INTELLIGENT OPERATING SYSTEM
- LARGE, DYNAMIC, DISTRIBUTED KNOWLEDGE BASE
- INTEGRATION OF DATA AND MODEL INFORMATION
- LAYERED, TRANSPARENT SOFTWARE

### **◦ INTELLIGENT HUMAN INTERFACES**

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

Background and Objectives

### ***Themes and Criteria for Prioritization***

**Martin M. Sokoloski / John Dalton**  
NASA Headquarters / NASA Goddard Space Flight Center

### **THEME SESSION OBJECTIVES**

#### **PURPOSE**

**IDENTIFY & PRIORITIZE TECHNOLOGIES FOR SENSORS,  
COMMUNICATIONS, AND INFORMATION SYSTEMS WHICH**

- **ARE CRITICAL FOR FUTURE U.S. SPACE PROGRAMS**
- **REQUIRE IN-SPACE TESTING AND VALIDATION**

#### **PRODUCT**

**HIGH PRIORITY TECHNOLOGIES AND RATIONALE FOR  
IN-SPACE EXPERIMENTATION:**

- **TECHNOLOGY NEED**
- **IMPORTANCE TO SPACE MISSIONS**
- **IN-SPACE TESTING REQUIRED**

### **THEME DESCRIPTION**

#### **SENSORS**

- **DEVICES & OPTICS**
- **LASERS**
- **PRECISION POINTING**
- **THERMAL MANAGEMENT & CRYOGENICS**

#### **COMMUNICATIONS**

- **OPTICAL & MICROWAVE**
- **POINTING, TRACKING, & ACQUISITION**

#### **INFORMATION SYSTEMS**

- **SPACE QUALIFIED PROCESSORS , STORAGE & COMPONENTS**
- **IMAGE & SIGNAL PROCESSORS**
- **DATA NETWORKS & TELEMETRY SYSTEMS**
- **AUTOMATED SYSTEMS**

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

Background and Objectives

***Themes and Criteria for Prioritization***

**Martin M. Sokoloski / John Dalton**

NASA Headquarters / NASA Goddard Space Flight Center

**CRITERIA FOR PRIORITIZATION**

- 1. CRITICALITY OF TECHNOLOGY IN ENABLING FUTURE U.S. SPACE MISSIONS**
- 2. POTENTIAL OF TECHNOLOGY FOR REDUCING COST (DEVELOPMENT, OPERATIONS, OR LIFE CYCLE)**
- 3. DEGREE TO WHICH TECHNOLOGY HAS BROAD APPLICATION TO A VARIETY OF SPACE MISSIONS**
- 4. REQUIREMENT FOR IN-SPACE VALIDATION TO EXPERIMENT WITH OR VERIFY PERFORMANCE IN MICRO-GRAVITY / THERMAL / RADIATION ENVIRONMENT OR TO REDUCE RISK FOR OPERATIONAL APPLICATIONS**

Theme 6 of 8

## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.1 Sensors

#### *In-Space Experiments in Remote Sensing Systems*

**Martin M. Sokoloski**

NASA Headquarters, Information Sciences & Human Factors Division

## INTRODUCTION/BACKGROUND

- **NASA R&D PROGRAMS**
  - **Detector Arrays**
    - Superconducting Bolometer Arrays
    - Impurity Band Conduction Detectors
    - III-V Material Arrays
    - Superlattice Detectors
  - **Heterodyne Systems**
    - Local Oscillators
      - Millimeter
      - Submillimeter
      - FIR
    - Mixers
    - Antennas (Radiometry)
      - 4M  $f > 100\text{GHz}$
      - 15-20M  $f < 100\text{GHz}$
    - Quasi-optics (Submillimeter)
  - **DIAL/LIDAR**
    - Lasers
      - Wavelength
      - Semiconductor Diode Array Pumps
      - CO<sub>2</sub> Systems
      - Solid State Lasers (amps)
      - All Solid State Systems
    - Detectors
  - **Coolers**
    - Single Stage
      - Pulse Tube
      - Mechanical
      - Dilution
      - Flux Compression
      - ADM
    - Multi-Stage

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

***In-Space Experiments in Remote Sensing Systems***

**Martin M. Sokoloski**

NASA Headquarters, Information Sciences & Human Factors Division

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

• **DETECTORS**

- Radiation Effects on Arrays
- Effects of Contaminants on Response of Detectors
- System Demonstration under Low Background Conditions
- Interaction of Coolers and Detector Systems
- Retrofit on In-Reach LITE System with New Detector Arrays & Refly
- Maintenance of Optical Surface Quality in Space with In-situ Cleaning Demonstration

• **HETERODYNE SYSTEMS**

- UV, Protons, and Electron Radiation Effects on Components & Systems
- Effect of Contaminants on System Performance
- Modify LITE Experiment for Single or Dual Channel for IR Radiometer for OH Measurement Demonstration
- Space Test of Large Unfilled Synthetic Aperture Radiometer (Requires Large Structure ~20 M Arms) for Proof of Concept
- Space Test of 30 and 118 Micrometer Heterodyne Imaging Spectrometer

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

*In-Space Experiments in Remote Sensing Systems*

**Martin M. Sokoloski**

NASA Headquarters, Information Sciences & Human Factors Division

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS (CONT'D)**

• **DIAL/LIDAR SYSTEMS**

- Retrofit LITE Platform with Tuneable Solid State Laser for DIAL Measurements Demo
- Retrofit 2 Micrometer Doppler Wind Shear Detector on LITE
- Demonstrate In-Space Operation of Semiconductor Diode Array Pumps
- Test of Picosecond Laser Ranging and Altimeter System
- In-Space Test of Laser System Stability

• **COOLER SYSTEMS**

- Microgravity Test of Liquid/Vapor Phase Separation in Joule-Thomson Refrigerators
- Microgravity Test of  $3\text{He}/4\text{He}$  Dilution Refrigerator Systems:
  - JPL System Concept
  - ARC System Concept
  - MSFC System Concept
- Extended Microgravity & Vacuum Test of Mechanical Coolers (10 kelvin and Above)
- Proof of Principle of Microgravity Operation of Subkelvin Coolers

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

***In-Space Experiments in Remote Sensing Systems***

**Martin M. Sokoloski**

NASA Headquarters, Information Sciences & Human Factors Division

**SUMMARY/RECOMMENDATIONS**

• **REQUIREMENTS FOR SENSOR SYSTEM IN-SPACE EXPERIMENTS**

- **Test of Operation in Space Radiation Environment**
- **Functioning in Micro- or 0-g Environment**
- **Operation in Vacuum**
- **Survive Launch**
- **Survive Shuttle Contamination**

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

*In-Space Sensor Technology Experiments*

E. David Hinkley  
Hughes Aircraft Company

**PURPOSE OF IN-SPACE  
SENSOR TECHNOLOGY EXPERIMENTS**

---

TO DEMONSTRATE:

1. FEASIBILITY
2. RELIABILITY
3. ENVIRONMENTAL COMPATIBILITY

**UNIQUENESS OF SPACE ENVIRONMENT  
FOR SENSOR SYSTEMS**

---

- NEAR-ZERO GRAVITY
- NONSTATIONARY PLATFORM
- SPECIAL SPACECRAFT ATMOSPHERES
- CONTAMINATION-INDUCED PERFORMANCE  
DEGRADATION
- STRONG RADIATION FLUX (UV, VIS, GAMMA)
- IN-VACUO WAVE PROPAGATION

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

***In-Space Sensor Technology Experiments***

**E. David Hinkley**  
Hughes Aircraft Company

**CATEGORIES FOR IN-SPACE SENSOR  
TECHNOLOGY EXPERIMENTS**

---

1. THERMAL MANAGEMENT, CRYOGENICS
2. OPTICS CONTAMINATION/DECONTAMINATION
3. PRECISION POINTING & TRACKING
4. LASER OPERATION

**SPACE APPLICATIONS**  
***Thermal Management, Cryogenics***

---

1. SENSOR/ELECTRONICS CRYOCOOLING
2. HEAT SWITCH FOR REDUNDANT CRYOCOOLER
3. WASTE HEAT TRANSFER TO RADIATOR
4. OPTICS CRYOCOOLING

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

***In-Space Sensor Technology Experiments***

**E. David Hinkley**  
Hughes Aircraft Company

**SPACE APPLICATIONS**  
***Optics Contamination/Decontamination***

---

1. OPTICS FOR UV, VIS, IR ASTRONOMY
2. CRYOCOOLED SENSORS & ELECTRONICS

**SPACE APPLICATIONS**  
***Precision Pointing & Tracking***

---

1. LASER REMOTE SENSING
2. HIGH-RESOLUTION ASTRONOMY
3. FAINT-TARGET ASTRONOMY (LONG INTEGRATION)
4. EARTH OBSERVATIONS FROM GEOSYNCH ORBIT
5. DEEP-SPACE OPTICAL COMMUNICATION

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

***In-Space Sensor Technology Experiments***

**E. David Hinkley**  
Hughes Aircraft Company

**SPACE APPLICATIONS**  
***Lasers***

---

1. WEATHER-RELATED MEASUREMENTS
2. ATMOSPHERIC CHEMISTRY MEASUREMENTS
3. HIGH-SPEED OPTICAL COMMUNICATIONS
4. IN-SPACE MANUFACTURING

Theme 6 of 8

## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.1 Sensors

#### *LIDAR/Laser Sensors*

Dr. Denis Killinger  
University of South Florida

#### Selected List of Atmospheric Constituents and Parameters Measured by Lidar

Constituents	Laser Type	Accuracy*	Lidar Type	Range*
Dust, Clouds Volcanic Ash Smoke Plumes	Ruby, Nd:YAG	1-10%	Atmospheric Backscatter	10-50 Km
H <sub>2</sub> O, O <sub>3</sub> , SO <sub>2</sub> NO, NO <sub>2</sub> , N <sub>2</sub> O C <sub>2</sub> H <sub>2</sub> , CH <sub>4</sub> , HCl, CO, Hg	Dye, CO <sub>2</sub> , OPO, Excimer Co:MgF <sub>2</sub>	Variable, 1 ppb to 100 ppm	DIAL, Raman	1-5 Km
OH, Na, K, Li, Ca, Ca <sup>+</sup>	Dye	10 <sup>2</sup> - 10 <sup>7</sup> atoms/cc	Fluorescence	1-90 Km
<b>Parameters</b>				
Temperature, Pressure	Dye, Nd:YAG	1 K <sup>0</sup> 5 mbar	DIAL, Raman	1-30 Km
Wind Speed	CO <sub>2</sub>	0.5 m/s	Doppler	15 Km

\* Accuracy and Ranges given are typical values and depend upon individual lidar measurements.

#### SPACEBORNE OPPORTUNITIES

- Global Laser Remote Sensing

1. Detection of [H<sub>2</sub>O], [CO<sub>2</sub>], [O<sub>3</sub>]  
Temperature, wind speed from space;  
LITE, LASA, EAGLE

2. Range/Altimeter for Surface and Ice Pack  
Profile, Fault Line Movement

- In-Situ Sensors

- High Altitude (In-Situ) Sensors  
for Trace Gas Contamination

- Unique Spaceborne Problem Areas

- Power ( < 10 kw, Eff. > 5% )  
Heat Dissipation (Primary, A/D Modulators)
- Weight ( < 2000 kg )
- Zero Gravity (Liquids/Dye Lasers, Cooling)
- Size
- Lifetime (Consumable, Laser H.V.)
- Eye Safety (λ > 1.4 μm)

Theme 6 of 8

## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.1 Sensors

#### *LIDAR/Laser Sensors*

Dr. Denis Killinger  
University of South Florida

#### Critical Technologoy

##### 1) Laser Development

- Diode Laser Pumping of Existing Lasers
- New Tunable (MID-IR) Laser Sources
  - Ho:YAG                      Nd:Glass/Raman Shift
  - Tl:Sapphire              Single-Frequency (Nd, etc.)
  - Er:YAG/OPD              Local Oscillator  
                                      (cw/Rapid Wide Tunability)
- Lifetime Issues
  - CO<sub>2</sub>/Catalyst
  - H.V./Electrodes

##### 2) LIDAR Deployment

###### LITE (Laser In-Space Technology Exp.)

- Nd:Y AG (2x, 3x)
  - 1st Spaceborne LIDAR
- Phase II: Tl:Sapphire

###### LASA/EOS

- LIDAR (use to correct passive)
- DIAL
- Altimetry

###### LAWS (WINDSAT)

- CO<sub>2</sub>/Doppler (Lifetime)
- Nd:YAG (L.O. Tracking)

###### Ozone (Excimer/Raman Shift)

###### Pointing/Tracking Accuracy

- Small Footprint (more severe than Radar)  
(Laser/Telescope Overlap)
- Push-Broom Scan
- Effect of Atmospheric Turbulence  
(Motion /Tracking)

##### 3) Laser Sensor

Absorption/Fluorescence Sensors  
(Trace Species In-Situ)

- Fiber/Optical Coupling
- Tunable Microlaser Sensors

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.1 Sensors

***LIDAR/Laser Sensors***

**Dr. Denis Killinger**  
University of South Florida

Road Map (LIDAR/SENSORS)

LIDAR Development

1. Space Shuttle Test of Simple LIDAR (Nd:YAG): LITE
2. Spaceborne LIDAR/Diode Pumped Nd:YAG
  - Direct & Coherent Detection (Limited power)
3. Coherent Doppler (Nd & CO<sub>2</sub>)
  - L.O. Tracking
4. Atmospheric Density/H<sub>2</sub>O for Passive Corrections
5. Altimeter/Surface Profiler LIDAR

LASER Development

1. Long-Life Nd:YAG
2. Diode-Laser Pumped Nd:YAG
3. Ho:YAG
4. Tunable Ti:Al<sub>2</sub>O<sub>3</sub>
5. Tunable Local Oscillator

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

### **6.2 Communications**

#### ***In-Space Experiments in Communication Systems***

**Martin M. Sokoloski**

NASA Headquarters, Information Sciences & Human Factors Division

## **INTRODUCTION/BACKGROUND**

- **Optical Communication System Elements**
  - Lasers & Laser Systems
  - Modulation Techniques
  - Detection (Coherent, Non-coherent)
  - Optics
  - Electronics
- **Space Qualification**
  - Space Radiation Environment/Energetic Particles
  - Vacuum
  - Microgravity
  - Spacecraft Charging and Outgassing
- **Laser Systems Not Space Demonstrated**
- **NASA R&D Programs**
  - **Laser Sources**
    - AlGaAs
    - Semiconductor Diode Laser Array
    - Pumped Solid State Laser Rods & Slabs
  - **Detection**
    - Coherent
    - Non-coherent
  - **Modulation Techniques**
  - **Electronics**

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## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

### **6.2 Communications**

#### ***In-Space Experiments in Communication Systems***

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NASA Headquarters, Information Sciences & Human Factors Division

## **MISSION APPLICATIONS**

- **Mission to Planet Earth**
  - GEO/GEO for Geoplat
  - GEO/LEO for Geoplat & Eos
  - GEO/Earth
- **Planetary**
  - Mars Rover
  - Cassini
  - Others
- **Solar Physics**
  - Star Probe (Enabling)

## **TECHNOLOGY NEEDS**

- **Free-Space Optical Communications "Revolutionary" Technology**
- **Breadboard In-space Demo Needed**
- **Component Space Qualification**
  - Laser & Laser Power
  - Pointing & Control (Closed and Open Loop)
  - Modulation Rate Demo
  - Demo of Space/Ground Link
  - Demo Space/Space Link

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**SENSORS AND INFORMATION SYSTEMS**

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6.2 Communications

***In-Space Experiments in Communication Systems***

**Martin M. Sokoloski**

NASA Headquarters, Information Sciences & Human Factors Division

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- **In-space Breadboard Demo of "Revolutionary" Technology**
  - **Space-Space**
  - **Space/Ground**
  - **Closed & Open Loop Acquisition**
  - **Coherent/Non-coherent Links**

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## SENSORS AND INFORMATION SYSTEMS

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### 6.2 Communications

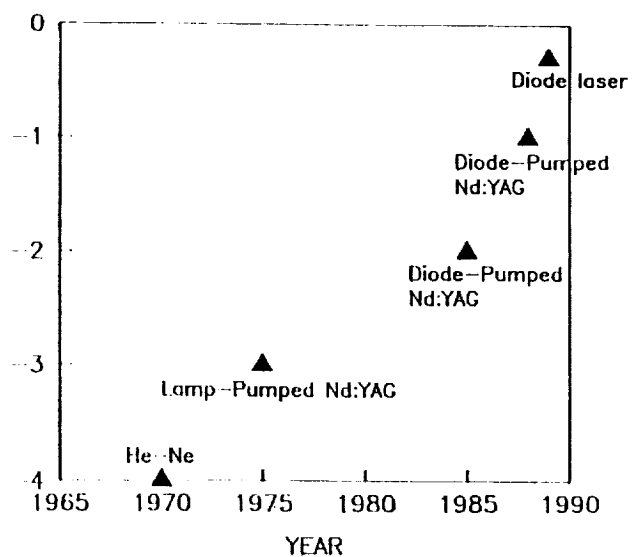
#### *Space Laser Communication Experiments*

**M. Ross**  
Laser Data Technology, Inc.

## SEMICONDUCTOR LASER BREAKTHROUGH

- HIGH EFFICIENCY
  - GREATER THAN 50% ACHIEVED
- UNIFORMITY ACHIEVED
  - ARRAYS FEASIBLE
- MULTI-WATT OUTPUTS ACHIEVED

### EFFICIENCY TRENDS FOR VISIBLE AND NEAR IR LASERS LOG OF LASER EFFICIENCY



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**SENSORS AND INFORMATION SYSTEMS**

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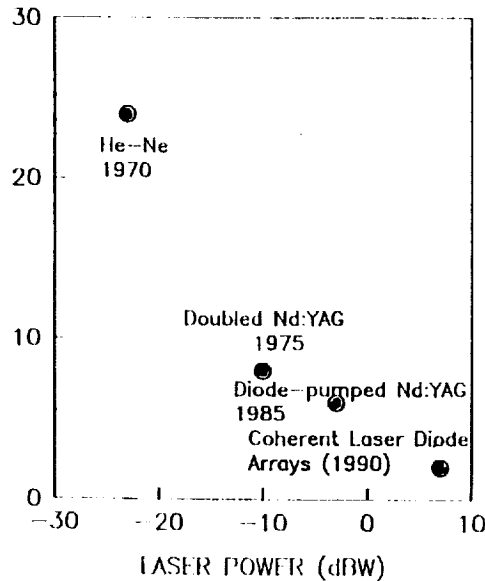
6.2 Communications

***Space Laser Communication Experiments***

**M. Ross**  
Laser Data Technology, Inc.

**LASER POWER/OPTICS SIZE TREND FOR SPACE LASERCOM  
(Direct Detection)**

REQUIRED OPTICS DIAMETER TO CLOSE LINK (INCHES)



**TECHNOLOGY TREND**

Photonics Capabilities Advancing Rapidly

Greater Solid State Laser Power Achievable at Higher Efficiency and Lower Cost

Enables Use of More Tolerant Designs in Rest of System

- Smaller, Less Precise Optics
- Easier Tracking Systems
- Less Integration and Test Costs

Enables Lower Weight, Lower Power, Lower Cost Laser Communication Systems

- 100lb, 100 watt Systems Will Become Achievable for Long-Distance Satellite-to-Satellite Links

Theme 6 of 8

## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.2 Communications

#### *Space Laser Communication Experiments*

**M. Ross**  
Laser Data Technology, Inc.

#### SUMMARY

- . POTENTIAL OF LASER COMMUNICATIONS UNTAPPED
- . HISTORY OF SPACE LASERCOM EXPERIMENTS
  - MANY STARTS, NO FINISHES
  - LACK OF GOVERNMENT COMMITMENT TO FOLLOW THRU
- . TECHNOLOGY STATUS
  - ABLE TO SUPPORT EXPERIMENTS
- . SPACE EXPERIMENT NEEDED FOR VALIDATION
  - HARDWARE
  - RELIABILITY
  - CONCEPTS

#### SPACE LASERCOM EXPERIMENTS

<u>LINK</u>	<u>DATA RATES</u>	<u>NOTES</u>
ONE-TO-ONE	1 to 5 Mbps > 300 Mbps	SCIENTIFIC PAYLOADS; IMAGES; SENSOR DATA REAL TIME HIGH RESOLUTION IMAGERY
MANY-TO-ONE	1 to 5 Mbps	MULTIPLE ACCESS
ONE-TO-MANY	< 20 Kbps	COMMAND CONTROL

#### RECOMMENDATIONS

- . DON'T TRY AND DEMONSTRATE TOO MUCH
  - . NASA SPONSOR ONE LOW-COST SIMPLE SPACE EXPERIMENT THAT
    - VALIDATES CONCEPT
    - DEMONSTRATE COMPONENT RELIABILITY
    - DEMONSTRATES BASIC SUBSYSTEMS SUCH AS
      - ACQUISITION
      - TRACKING
      - LASER TRANSMITTER
      - LASER RECEIVER
  - . RANGE NOT CRITICAL; COULD BE SHORT RANGE
- EXAMPLE: SHUTTLE TO FREE FLYER

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

### **6.2 Communications**

#### ***Coherent Optical Intersatellite Crosslink Systems***

**Vincent W.S. Chan**  
Massachusetts Institute of Technology

### **LASERCOM CROSSLINK TECHNOLOGY**

- **CANDIDATE SYSTEM TECHNOLOGIES**
  - **DIRECT DETECTION (Incoherent)**
  - **HETERODYNE (Coherent)**
- **HETERODYNE RECEIVER 15 dB MORE SENSITIVE THAN DIRECT DETECTION**
- **HIGH ANTI-JAM CAPABILITY**
- **SMALLER APERTURE ALLOWS EASIER SPACECRAFT INTEGRATION**
- **USE OF HIGH EFFICIENCY (15%) GaAlAs SEMICONDUCTOR LASERS**
- **LINCOLN LABORATORY LASER INTERSATELLITE TRANSMISSION EXPERIMENT (LITE)**

### **LASER CHARACTERISTICS FOR COHERENT SYSTEMS APPLICATIONS**

- **HIGH OUTPUT POWER**
  - **SIZE, WEIGHT, POINTING, MARGIN**
- **SINGLE SPATIAL MODE**
  - **USEFUL POWER IN FAR FIELD**
- **SINGLE FREQUENCY**
  - **HETERODYNE RECEIVER**
- **TUNABLE WAVELENGTH**
  - **WAVELENGTH MATCH, TRACKING**
- **DIRECT MODULATION**
  - **EQUALIZABLE FM TRANSFER FUNCTION**
- **NARROW LINEWIDTH**
  - **SPECTRAL SPREADING IMPACT ON BER**
- **STABLE, RELIABLE LIFE**
  - **>50,000 hr GOAL**

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

### **6.2 Communications**

#### ***Coherent Optical Intersatellite Crosslink Systems***

**Vincent W.S. Chan**  
Massachusetts Institute of Technology

### **OPTICAL/MECHANICAL/THERMAL DESIGN ISSUES**

- **OPTICAL DESIGN**
  - MAINTAIN THROUGHPUT, WAVEFRONT QUALITY
  - PROVIDE ACCURATE POINTING
- **MECHANICAL DESIGN**
  - PROVIDE STIFFNESS, STABILITY TO MAINTAIN OPTICAL ALIGNMENT, POINTING ACCURACY
  - ISOLATE AGAINST SPACECRAFT DISTURBANCES
- **THERMAL DESIGN**
  - MINIMIZE AND STABILIZE TEMPERATURE GRADIENTS UNDER VARYING THERMAL SCENARIOS

### **HETERODYNE RECEIVER TECHNOLOGY**

- **LOW-NOISE/WIDEBAND FRONT END**
  - NEAR-QUANTUM-LIMITED 1 GHz FRONT END DEMONSTRATED (LITE)
  - FURTHER DEVELOPMENT REQUIRED TO EXTEND BANDWIDTH AT QUANTUM LIMIT
- **FREQUENCY-LOCKING**
  - DONE ROUTINELY FOR FSK (LITE)
- **PHASE-LOCKING**
  - DIFFICULT WITH PRESENT LASER LINEWIDTHS

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

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6.2 Communications

***Coherent Optical Intersatellite Crosslink Systems***

Vincent W.S. Chan  
Massachusetts Institute of Technology

**SPATIAL ACQUISITION**

- **LARGE INITIAL POINTING UNCERTAINTY**
  - **DOMINATED BY SPACECRAFT ATTITUDE CONTROL ERROR**  
(~ 1 mRAD Typical)
  - **SMALL COMMUNICATIONS BEAMWIDTH (4  $\mu$ rad In LITE)**
- **SEARCH OVER MANY SPATIAL "CELLS" REQUIRED**
- **CCD TECHNOLOGY WILL PERMIT RAPID ACQUISITION**  
(Few Seconds)

**CRITICAL TECHNOLOGY DEVELOPMENT NEEDS FOR  
SPACE LASER COMMUNICATION SYSTEMS**

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- **ASSESSMENT OF STATE-OF-THE-ART TECHNOLOGY**
- **EXAMINE INTERPLAY BETWEEN TECHNOLOGY AND  
SYSTEM DESIGNS**
- **SOUND FLEXIBLE DESIGN**
- **ON-ORBIT DEMONSTRATION AND EXPERIMENTATION**
  - 1. **SPATIAL ACQ / TRACK EXECUTION AND EXPERIMENTATION**
  - 2. **OPTICAL / MECHANICAL / THERMAL DESIGN VERIFICATION**
  - 3. **USE OF EXPERIENCE GAINED FOR THE DESIGN OF OPERATIONAL SYSTEMS**

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.2 Communications

***Coherent Optical Intersatellite Crosslink Systems***

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Massachusetts Institute of Technology

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## CONCLUSIONS

- COHERENT TECHNOLOGY IS READY FOR SPACE  
CROSSLINK APPLICATIONS
- IT OFFERS SMALL APERTURE SIZE, MODEST WEIGHT  
AND POWER
- WITH COMMERCIALY AVAILABLE COMPONENTS,  
SEVERAL HUNDRED Mbps CAN BE SUPPORTED WITH  
20 cm TELESCOPES

Theme 6 of 8

## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.3 Information Systems

#### *In-Space Experiments in Information Systems*

John T. Dalton

NASA Goddard Space Flight Center, Data Systems Technology Division

## INTRODUCTION/BACKGROUND

### o INFORMATION SYSTEMS ELEMENTS:

- SPACE-QUALIFIED PROCESSOR SYSTEMS AND COMPONENTS
- HIGH-SPEED IMAGE AND SIGNAL PROCESSING
- HIGH CAPACITY STORAGE
- ON-BOARD LOCAL AREA NETWORKS AND DATA HANDLING SUBSYSTEMS
- AUTOMATED SYSTEMS AND FAULT TOLERANT SYSTEMS

### CURRENT NASA CAPABILITY

#### • PROCESSORS:

NSSC-1, SHUTTLE COMPUTERS, 1750A PROCESSORS, HARRIS 80C86 (MARS OBSERVER)

PLANNED : SPACE STATION FREEDOM INTEL/IBM 80386, CRAFT/CASSINI SANDIA 32016

#### • IMAGE PROCESSING:

NONE

#### • HIGH CAPACITY STORAGE:

LONGITUDINAL TAPE RECORDERS, VHS-BASED HELICAL SCAN(MANNED MISSIONS)

#### • ON-BOARD DATA HANDLING:

MISSION-UNIQUE

#### • AUTOMATED SYSTEMS:

PRIMARILY LIMITED TO PROCESS CONTROL PROCEDURES, WITH SOME AUTOMATED FAULT PROTECTION

### NASA R&D PROGRAMS

#### • PROCESSORS:

FAULT TOLERANT MULTIPROCESSOR SYSTEM (LaRC, JPL)

FLIGHT SYMBOLIC PROCESSOR WITH RH32 NUMERIC PROCESSOR (ARC)

#### • IMAGE PROCESSING:

GaAs BIT SLICE PROCESSOR PIPELINE (GSFC)

MULTISPECTRAL IMAGE COMPRESSION/PROCESSING (JPL, GSFC)

#### • HIGH CAPACITY STORAGE:

SPACE OPTICAL DISK RECORDER - 160 Gbit capacity, 300 Mbps (LaRC)

ROTARY HEAD TAPE RECORDER HEAD LIFE TESTING (GSFC)

MEDIUM RATE (20 Mbps) LONGITUDINAL RECORDER (GSFC)

#### • ON-BOARD DATA HANDLING:

FIBER OPTIC TRANSCEIVERS (LaRC)

HIGH RATE ARCHITECTURE (GSFC)

CCSDS STANDARD FORMAT DATA HANDLING SYSTEMS (GSFC)

#### • AUTOMATED SYSTEMS:

• SYSTEMS AUTONOMY DEMONSTRATIONS FOR SPACE STATION FREEDOM  
(POWER AND THERMAL SYSTEM CONTROL) - (ARC, JSC, LaRC)

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

### **6.3 Information Systems**

#### ***In-Space Experiments in Information Systems***

**John T. Dalton**

NASA Goddard Space Flight Center, Data Systems Technology Division

### **TECHNOLOGY NEEDS**

#### **◦ SPACE-QUALIFIED PROCESSORS:**

- HIGHER PERFORMANCE 32-BIT PROCESSORS TO SUPPORT COMPLEX CONTROL OPERATIONS
- PROCESSOR MEMORY CAPACITY (4 TO 32 MBYTES):
  - REDUCE FLIGHT SOFTWARE DEVELOPMENT COST
  - SUPPORT ON-BOARD SENSOR CALIBRATION AND DATA COMPRESSION
  - REDUCE TDRS CONTACT TIME REQUIRED FOR PROCESSOR LOADS

#### **◦ IMAGE AND SIGNAL PROCESSING:**

- IMAGE COMPRESSION DEVICES TO REDUCE TELEMETRY BANDWIDTH
- PROCESSORS TO SUPPORT FEATURE AND INFORMATION EXTRACTION
- COMPRESSION OF TIME SERIES OF HIGH RESOLUTION IMAGES (MICRO GRAVITY EXPERIMENTS)

#### **◦ HIGH CAPACITY STORAGE:**

- DIRECT ACCESS STORAGE (50 MBYTES TO 10 GBYTES)
  - ON-BOARD MANAGEMENT AND PRIORITY PLAYBACK OF ENGINEERING DATA, CONTROL PROGRAM LOADS, IMAGE STORAGE FOR NEAR-REAL TIME PROCESSING
- HIGH RATE STORAGE (250 MBYTES @ 20 Mbps to 31GBYTES @ 300 Mbps)
  - LINK BUFFERING OF IMAGING SENSORS

#### **◦ NETWORKS AND DATA HANDLING SYSTEMS:**

- FAULT-TOLERANT, ADAPTABLE ON-BOARD DATA SYSTEMS THAT ARE OPERABLE (UPGRADABLE, MAINTAINABLE) ON-LINE FROM GROUND CONTROL CENTERS
- PACKET TELEMETRY INTERFACES
- SYSTEM CONTROL INTERFACES FOR RESOURCE ENVELOPE ENFORCEMENT

#### **◦ AUTOMATED SYSTEMS:**

- REAL-TIME EXPERT SYSTEMS FOR SENSOR AND SYSTEM CONTROL
- ON-BOARD RESOURCE MANAGEMENT AND CONTROL

### ***ISSUE***

**LARGE GAP EXISTS BETWEEN PERFORMANCE CAPABILITY OF GROUND-BASED INFORMATION SYSTEMS AND SPACE QUALIFIED SYSTEMS:**

- SPACE ENVIRONMENT REQUIREMENTS: RADIATION, THERMAL, LAUNCH STRESS
- POWER AND WEIGHT CONSTRAINTS

**ADVANCED MISSION CONCEPTS TEND TO BE BASED ON TECHNOLOGY CAPABILITY OF GROUND SYSTEMS, AND MUST BE SUBSTANTIALLY DESCOPE TO BE IMPLEMENTABLE IN PROVEN FLIGHT TECHNOLOGY.**

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## **SENSORS AND INFORMATION SYSTEMS**

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### **6.3 Information Systems**

#### ***In-Space Experiments in Information Systems***

**John T. Dalton**

NASA Goddard Space Flight Center, Data Systems Technology Division

### **MISSION APPLICATIONS**

#### **o ON-BOARD SYSTEM AND SENSOR CONTROL AND DATA PROCESSING APPLICATIONS GENERALLY APPLICABLE TO MOST SPACE MISSIONS:**

- **INTELLIGENT SENSORS FOR LONG TERM MONITORING OF PHENOMENA AND FOR ADAPTIVE OBSERVATION OF SCIENTIFICALLY INTERESTING EVENTS**
- **ON-BOARD SENSOR CALIBRATION AND PROCESSING**
- **ON-BOARD CONTROL OF COORDINATED MULTI-SENSOR OBSERVATIONS**
- **ON-BOARD FAULT DETECTION AND RECONFIGURATION OF SPACECRAFT SYSTEMS**
- **COMPRESSION, BUFFERING, AND ON-BOARD PROCESSING FOR HIGH RATE IMAGING INSTRUMENTS**
- **DATA DRIVEN TELEMETRY SYSTEMS (USING PACKET TELEMETRY STANDARDS)**
- **ON-BOARD RESOURCE CONTROL TO IMPROVE RESPONSIVENESS OF SCIENCE OPERATIONS**

#### **• SUPPORTING PROCESSOR TECHNOLOGY FOR ROBOTICS:**

- **TASK PLANNING**
- **SENSING AND REACTIVE CONTROL**
- **MACHINE VISION**

### **IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

#### **o PROCESSORS:**

- **DEMONSTRATE SPACE-QUALIFIED, FAULT TOLERANT PROCESSORS AND MEMORY SYSTEMS**
  - **WITH ACCEPTABLE POWER AND WEIGHT CHARACTERISTICS**
  - **SUFFICIENT SPACE ENVIRONMENT OPERATION TO VERIFY PERFORMANCE**

#### **o IMAGE PROCESSORS:**

- **DEMONSTRATE SPACE-QUALIFIED PROCESSORS FOR HIGH RATE LOSSLESS IMAGE COMPRESSION**
- **DEMONSTRATE SPACE-QUALIFIED PROCESSORS PROGRAMMABLE FOR MULTISPECTRAL IMAGE FEATURE EXTRACTION**

#### **o STORAGE:**

- **DEMONSTRATE LAUNCH SURVIVAL AND IN-SPACE OPERATION OF MOVING MEDIA STORAGE DEVICES**
- **LONG DURATION EXPOSURE OF MATERIAL AND COMPONENTS TO RADIATION ENVIRONMENTS (LASERS, WRITE-ONCE AND ERASABLE MEDIA, ETC.)**

#### **o NETWORKS AND DATA HANDLING SYSTEMS:**

- **DEMONSTRATE SOFTWARE AND SYSTEM RECONFIGURATION WHILE MAINTAINING RELIABLE OPERATIONS**
- **DEMONSTRATE SPACE-QUALIFIED COMPONENTS FOR TELEMETRY GENERATION AND HANDLING SUPPORTING CCSDS PACKET TELEMETRY STANDARDS**

#### **o AUTOMATED SYSTEMS:**

- **DEMONSTRATE IN-SPACE OPERATION OF AUTOMATED EXPERIMENT AND SUBSYSTEM OPERATIONS**
- **DEMONSTRATE OPERATION OF AUTOMATED RESOURCE MANAGEMENT SUBSYSTEMS**  
(E.G., RESOURCE ENVELOPE ALLOCATION, RESOURCE CHECKING, COMMAND CHECKING, INTERLOCKS)

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

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### **6.3 Information Systems**

#### ***In-Space Experiments in Information Systems***

**John T. Dalton**

NASA Goddard Space Flight Center, Data Systems Technology Division

### **SUMMARY/RECOMMENDATIONS**

- o **REQUIREMENTS FOR INFORMATION SYSTEMS IN-SPACE EXPERIMENTS**
  - **SUCCESSFUL LONG DURATION EXPOSURE TO AND OPERATION IN RADIATION ENVIRONMENT**
  - **ACCEPTABLY LOW POWER AND WEIGHT REQUIREMENTS**
  - **LAUNCH SURVIVAL AND ZERO-G OPERATION PRIMARILY FOR MOVING MEDIA STORAGE DEVICES**
  - **SMART SENSOR SYSTEMS TESTED IN OBSERVATIONS FROM SPACE**
  - **AUTONOMOUS SYSTEMS: SUFFICIENT TESTING TO ELIMINATE PERCEIVED RISK**

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## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.3 Information Systems

#### *Information System Panel DMS Perspectives — December '88*

George Nossaman  
IBM, Federal Systems Division

#### RATIONALE FOR IN-SPACE TECHNOLOGY EXPERIMENTS

##### "DMS PERSPECTIVES"

- SPACE TESTING GENERALLY EXPENSIVE
- ENVIRONMENT CAN NOT BE ACCURATELY SIMULATED IN GROUND LABS

<u>GROUND-SUFFICIENT</u>	<u>IN-SPACE</u>
THERMAL	ZERO-G
VACUUM	RADIATION (COMPLETE)
EMC	MULTIPLE EFFECTS
VIBRATION	
RADIATION (PARTIAL)	
- CONFIDENCE - BUILDING
  - ON-ORBIT TESTING RAISES CONFIDENCE IN SYSTEM APPROACH
  - DOES NOT COVER ALL PROBLEM AREAS
- SOME OPERATIONAL INTERACTIONS - INVOLVING HUMANS CANNOT BE ACCURATELY SIMULATED
  - TELEOPERATIONS W/ROBOTS
- SPACE TESTING:
  - SHOULD VERIFY TECHNIQUES, SYSTEM APPROACHES WHICH CANNOT BE TESTED ON THE GROUND
  - SHOULD NOT BE USED AS BASIS FOR DEVELOPMENT OF NEW CONCEPT, OR PRIMARY TESTING APPROACH

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## SENSORS AND INFORMATION SYSTEMS

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### 6.3 Information Systems

#### *Information System Panel DMS Perspectives — December '88*

George Nossaman  
IBM, Federal Systems Division

#### TRENDS IN SPACE DATA SYSTEMS

- SYSTEM ARCHITECTURES
  - MOVING TOWARD DISTRIBUTED APPROACHES
  - MERGING WITH GROUND-BASED SYSTEMS - GENERAL PURPOSE H/W
  - INCREASING USE OF STANDARDS FOR LCC REDUCTION
  - DIFFERING MILITARY/CIVILIAN APPROACHES
- NETWORKS
  - EMERGING NEED FOR HIGH SPEED (>50 Mb/s)
  - CONTINUING NEED FOR SIMPLE INSTRUMENTATION BUSES, LOCAL I/O
  - EMERGING NEED FOR 10 Mb/s LAN
  - FIBER OPTICS REPLACING CABLE/WIRE BUSES
- PROCESSORS
  - HIGH SPEED, SINGLE BOARD + SINGLE CHIP PROCESSORS (32 BITS)
  - LOOSELY-COUPLED ARRAYS OF PROCESSORS
  - TIGHTLY COUPLED SYSTEMS (MILITARY/SENSOR SYSTEMS)
  - ON-BOARD HIGH-SPEED VECTOR PROCESSING
  - SILICON MEMORY WITH ECC & SCRUB
  - USE OF COMMERCIAL/MILITARY SYSTEMS IN SPACE
  - USE OF COTS S/W, GENERAL PURPOSE OS
- MASS STORAGE
  - MOVING TOWARD WINCHESTER-DISK MASS STORAGE
  - OPTICAL MEMORY
  - INTEGRATED DATA BASE APPROACHES

#### RADIATION EFFECTS ON DIGITAL ELECTRONICS

##### BACKGROUND

- FAILURE MODES
  - SINGLE-EVENT UPSET SEU
  - LATCH-UP
  - TOTAL DOSE
- VARIATIONS IN SPACE ENVIRONMENT
  - ORBITAL HEIGHT
  - ORBITAL INCLINATION
  - SOLAR CYCLES
  - RANDOM EVENTS (FLARES, ETC)
  - MAN-MADE EVENTS (NUCLEAR EFFECTS)
  - SHIELDING
  - PARTICLE FLUX CHARACTERISTICS
- GROUND TESTING LIMITATIONS
  - RADIATION SPECTRA
  - MODELING ACCURACY
  - CIRCUIT COMPLEXITY
  - EFFECTS REPORTING

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

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**6.3 Information Systems**

**Information System Panel DMS Perspectives — December '88**

**George Nossaman**  
IBM, Federal Systems Division

IN-SPACE TECHNOLOGY TESTING NEEDS

SPACE DATA SYSTEM  
NEED EXAMPLES

IN-SPACE TESTING RATIONALE

COMPONENTS	ZERO-G ENVIRONMENT	SINGLE-EVENT EFFECTS	TOTAL-DOSE EFFECTS	OPERATION COMPLEXITY	CONFIDENCE
VHSIC PROCESSES	X	X	X		X
"COMMERCIAL" PROCESSES-SILICON	X	X	X		X
"NEW COMPONENT" TECH-n g OPTICAL (DRIVES)	X	X	X		X
PROCESSORS					
NEW ISA SYSTEMS		X	X		X
ARRAY PROCESSORS					X
HIGH-SPEED BACKPLANES					X
FAULT-TOLERANT ARCHITECTURES					X
NETWORKS					
NEW MEDIA		X	X		X
ROTATING JOINT MISSION					X
NETWORK SYSTEMS		X	X		X
DRIVER/RECEIVER TECHNOLOGIES					X
MASS STORAGE					
ROTATING SYSTEMS	X				X
OPTICAL DRIVERS/RECEIVERS		X	X		X
MEDIA STABILITY		X	X		X
SOFTWARE					
OPERATING SYSTEMS					X
DMS's					X
NETWORK OS					X
AI SYSTEMS					X
SYSTEMS					
TELE OPERATIONS				X	X
AUTOMATED SYSTEMS				X	X

IN-SPACE TESTING NEEDS GENERAL

- INEXPENSIVE WAY TO TEST COMPONENTS IN SPACE FOR SEE
- INEXPENSIVE WAY TO VERIFY SYSTEMS FOR SEE, INTEGRATED EFFECTS
- LONG DURATION TEST FACILITY FOR LIFETIME TESTING - TOTAL DOSE, INTEGRATED EFFECTS
- COORDINATED GROUND TEST, MODELING PROGRAM
  - PROGRAM AND FACILITY FOR MULTIPLE EFFECTS
- ORGANIZED APPROACH TO SELECT TECHNOLOGIES WHICH REQUIRE, RECEIVE TESTING
- SIMPLE WAY TO FLY "COMMERCIAL" AND/OR "MILITARIZE" ELECTRONICS FOR QUICK EVALUATION

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.3 Information Systems

***Information System Panel DMS Perspectives — December '88***

**George Nossaman**  
IBM, Federal Systems Division

SPECIFIC SUGGESTIONS

- ESTABLISH COMPONENTS & SYSTEMS TESTING PROGRAM
  - COMPONENTS & SYSTEM TEST STANDARDS
  - USE STATION AS A PATHFINDER
- DEVELOP A CONCEPT FOR LONG DURATION "COMPONENTS & ELEMENTS" TEST FIXTURES
  - PERHAPS SEVERAL AT VARIOUS DURATION AND ORBITS
- EXPAND INEXPENSIVE SORTIE-LEVEL TESTING CAPABILITIES
  - TEST COMPONENTS
  - VERIFY SYSTEM ELEMENTS
  - FLY UNMODIFIED COMMERCIAL/MILITARY TECHNOLOGY

Theme 6 of 8

## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.3 Information Systems

#### *In-Space Experiments in Information Systems*

Nell R. White

University of Colorado, Laboratory for Atmospheric and Space Physics

#### UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS

- THE CATCH-22 OF SPACE INSTRUMENTATION
  - PROPOSALS ARE OFTEN AWARDED BASED UPON CONSERVATIVE 'CANNOT FAIL' DESIGNS. AT THE SAME TIME COSTS MUST BE HELD DOWN AND DELIVERY BASED UPON SUCCESS ORIENTED SCHEDULES.
    - POWER, WEIGHT, AND ENVIRONMENTAL CONSTRAINTS AFFECT SCIENTIFIC OBJECTIVES, TYPICALLY REDUCING OVERALL SCIENTIFIC RETURN.
    - H/W SHOULD BE 'OFF-THE-SHELF', USING PARTS PREQUALIFIED FOR SPACE ENVIRONMENTS. THIS FORCES USING TECHNOLOGIES AND PARTS WHICH ARE FIVE OR MORE YEARS BEHIND COMMERCIALY AVAILABLE PARTS, AGAIN LIMITING SCIENTIFIC RETURN.
    - S/W IS LIMITED BY PROCESSOR, TECHNOLOGY (CMOS, LSTTL, HCMOS, ETC.), MEMORY SIZES, ETC., FORCING ROUTINES TO BE WRITTEN IN ASSEMBLY LANGUAGE. ALSO LIMITS CAPABILITIES TO SIMPLE CONTROL ALGORITHMS AND LOW DATA RATES.
  - YET WE LIVE IN A COMPLEX UNIVERSE, FORCING THE INSTRUMENTATION TO GROW IN COMPLEXITY AND SIZE.
    - EACH GENERATION MUST BE MORE SENSITIVE, HAVE A LARGER DYNAMIC RANGE, AND HIGHER PRECISION AND RESOLUTION THAN ITS PREDECESSOR
    - SHORT AND LONG TERM DRIFT (OVER TIME, TEMPERATURE, RADIATION, ETC) FORCE THE DEVELOPMENT OF COMPLEX, IN FLIGHT, CALIBRATION SEQUENCES
    - DATA VOLUME IF UNINTERESTING PHENOMENA IN A 'SIT AND WAIT' MODE IS EXCESSIVE. INSTRUMENTATION NEEDS TO BE ABLE TO FIND THE HIGH QUALITY DATA THAT WILL ENHANCE SCIENTIFIC DISCOVERIES
- MISSION APPLICATIONS FOR FUTURE SPACE QUALIFIED INFORMATION SYSTEMS
  - ON-BOARD SENSOR-BASED 'EVENT' DETECTION AND S/C MODE RECONFIGURATION FOR 'EVENT' OBSERVATION
    - SOLAR PHYSICS (FLARES, CORONAL MASS EJECTION, CORONAL HOLES, ETC)
    - ATMOSPHERIC PHYSICS (AURORA, POLAR MESOSPHERIC CLOUDS, ETC)
    - COMETARY PHYSICS (DETECTION, COMPOSITION)
    - PLANETARY EXPLORATION (VOLCANOS, RINGS, ETC.)
    - ASTROPHYSICS (SUPERNOVAS)
  - RESOURCE MANAGEMENT
    - POWER
    - TEMPERATURE
    - DISTURBANCE TORQUES
    - DATA (COMPRESSION, BUFFERING, RATES, PACKETIZING)
  - SENSOR CALIBRATIONS
  - FAULT DETECTION AND CORRECTION
  - POINTING, ATTITUDE, AND MOTION CONTROL AND COMPENSATION

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

6.3 Information Systems

***In-Space Experiments in Information Systems***

**Neil R. White**

University of Colorado, Laboratory for Atmospheric and Space Physics

**UNIVERSITY SCIENTISTS AND ENGINEERS PERSPECTIVES ON INFORMATION SYSTEMS  
(CONTINUED)**

- DIFFICULTIES EXPERIENCED RELATING TO DEVELOPMENT AND QUALIFICATION OF NEW FLIGHT TECHNOLOGIES
  - LIMITED PERSONNEL / EXPERIENCE BASE
  - AOS OFTEN PRECLUDE THE DEVELOPMENT OF NEW TECHNOLOGIES
  - NO PROFIT MOTIVE OR INTERNAL R & D FUNDING SOURCES
  - MOST FLIGHT PROGRAMS ARE UNWILLING TO ACCEPT THE RISKS ASSOCIATED WITH THE DEVELOPMENT OF NEW TECHNOLOGIES. SEPARATE GRANTS MUST BE OBTAINED PRIOR TO S/C FUNDING FOR DEVELOPMENT PROGRAMS
- UNIVERSITIES SUFFER FROM POOR OR CONFLICTING DATA PERTAINING TO SPACE QUALIFIED PARTS
  - EACH NASA CENTER USES DIFFERENT APPROVED PARTS AND FABRICATION TECHNIQUES
  - NEWER TECHNOLOGIES IN THE PROCESS OF QUALIFICATION ARE NOT WIDELY PUBLISHED
  - DOD SPACE QUALIFIED PARTS CANNOT BE OBTAINED
- LITTLE OR NO STANDARDIZATION OF S/C INTERFACES, BUS STANDARDS, ETC. THUS EVERY INSTRUMENTS DESIGN IS UNIQUE EVEN THOUGH MANY INCORPORATE SUBSYSTEM COMMON TO ALL
  - MICROPROCESSOR / BUS
  - ECC MEMORY
  - TELEMETRY INTERFACE
  - STANDARD INTERFACES (MULTICHANNEL A/D'S AND D/A'S, ETC)
  - SOFTWARE

**UNIVERSITY SCIENTISTS AND ENGINEERS WILL PUSH AVAILABLE FLIGHT DESIGNS AND TECHNOLOGIES TO THEIR LIMITS. HOWEVER, THEY WILL NOT PROPOSE INSTRUMENTATION REQUIRING THE DEVELOPMENT OR QUALIFICATION OF NEWER, COMMERCIALY AVAILABLE PARTS AND TECHNOLOGIES, UNDER S/C ANNOUNCEMENT OF OPPORTUNITIES.**

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## SENSORS AND INFORMATION SYSTEMS

Theme 6 of 8

### 6.3 Information Systems

#### *In-Space Experiments in Information Systems*

**Neil R. White**

University of Colorado, Laboratory for Atmospheric and Space Physics

#### TECHNOLOGY NEEDS

- INTELLIGENT (NETWORKED) INSTRUMENTATION AND S/C
  - ON-BOARD CALIBRATION SEQUENCING
    - S/C MANEUVERING
    - INSTRUMENT CONFIGURATION
    - SENSOR DATA CALIBRATION ANALYSIS
    - STORAGE OF CALIBRATION DATA
  - REAL-TIME DATA PROCESSING
    - APPLICATION OF CALIBRATION DATA
    - BACKGROUND REMOVAL
    - ANALYTICAL ANALYSIS (MIN / MAX, FFT, MODEL FITTING, ETC.)
    - DATA COMPRESSION
  - DATA ANALYSIS
    - 'EVENT' DETECTION AND FEATURE RECOGNITION
  - 'EVENT' BROADCAST AND RECONFIGURATION
    - INSTRUMENT
    - S/C
    - OTHER (OTHER S/C, GROUND INSTRUMENTATION, SS INSTRUMENTATION, ETC.)
  - RESOURCE MANAGEMENT
- SPACE-QUALIFIED PARTS / SYSTEMS
  - STANDARDIZED BUS PROTOCOL(S)
    - 'OFF-THE-SHELF' SPACE-QUALIFIED COMPONENTS
      - 8, 16, & 32 BIT FAULT TOLERANT MICROPROCESSOR CARDS
      - ECC MEMORY (PROM, EPROM, SRAM, AND DRAM)
      - TELEMETRY INTERFACE CARDS (SHOULD COMPLY WITH COMMERCIALLY AVAILABLE STANDARDS LIKE RS-232, IEEE-488, ETHERNET, ETC.)
      - CONTROL VF CARDS (DIGITAL I/O, A/D, D/A, ETC.)
      - LITERALLY SPACE QUALIFIED PC'S, MAC II'S, MICROVAX'S, ETC. WITH PLUG IN PERIPHERAL CARDS
  - SOFTWARE UTILITIES SUPPORTING HARDWARE SYSTEMS
    - REAL-TIME MULTITASKING KERNEL
    - PACKET GENERATION UTILITIES
    - DATA COMPRESSION UTILITIES
    - COMMAND ERROR CHECKING AND PARSING UTILITIES
    - GROUND BASED COMPLEMENTS TO THE ABOVE UTILITIES
    - RESOURCE MANAGEMENT UTILITIES
- NATIONAL NASA APPROVED PARTS AND SOFTWARE DATABASE
  - CONTINUOUSLY UPDATED
    - DISCRETE PARTS AND MATERIALS
    - COMPONENT LEVEL CARDS / BOARDS
      - SPECIFICATIONS
      - QUALIFICATION LEVEL (MIL-STD-883, MIL-M-38510, ETC.)
      - RADIATION HARDNESS
      - VENDOR
      - PRICE
    - SOFTWARE UTILITIES
    - CURRENT R & D EFFORTS
    - USER FEEDBACK / WISH LISTS

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**SENSORS AND INFORMATION SYSTEMS**

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6.3 Information Systems

***In-Space Experiments Information Systems Critical Technology Requirements***

**Martin M. Sokoloski / John Dalton**  
NASA Headquarters / NASA Goddard Space Flight Center

**SENSORS IMPORTANCE**

**MISSION TO PLANET EARTH**

**EOS**

**Laser Active Sensing of Winds**

**Laser Active Sensing of Trace Species**

- **Ozone, Acid Rain, H<sub>2</sub>O, CO<sub>2</sub>, Others**

**Laser Altimetry**

- **Plate Tectonic Movements**

**GEOPLAT**

**Fixed Focus with Large Format Arrays**

**Multi-Spectral Imagers**

**Spatial Imagers**

**SENSORS IN-SPACE TESTING REQUIRED**

- o **IN-SPACE POINTING, CONTROL & STABILIZATION TEST BED FOR DETECTORS & LASERS REMOTE SENSING SYSTEMS**
- o **IN-SPACE TESTING, DEMONSTRATION, AND VERIFICATION OF PROTOTYPE COOLERS & COOLER SYSTEMS**
  - **Mechanical Refrigerators**
  - **Magnetic Refrigerators**
  - **He<sup>3</sup>/He<sup>4</sup> Dilution Refrigerators**

Theme 6 of 8

## **SENSORS AND INFORMATION SYSTEMS**

Theme 6 of 8

### **6.3 Information Systems**

#### ***In-Space Experiments Information Systems Critical Technology Requirements***

**Martin M. Sokoloski / John Dalton**  
NASA Headquarters / NASA Goddard Space Flight Center

### **SENSORS TECHNOLOGY NEEDS**

- o **PRECISION POINTING, CONTROL & STABILIZATION FOR PASSIVE AND ACTIVE (DIAL/LIDAR) REMOTE SENSING**
  - o **Passive Sensing (Detector Arrays)**
    - "Earth Looking"
    - "Out Looking"
  - o **Active Sensing**
    - Differential Absorption LIDAR
    - Coherent Doppler LIDAR [Laser Atmospheric Wind Sounder]
- o **SPACE - QUALIFIABLE COOLERS & COOLER SYSTEMS OPERATING IN 0-G ENVIRONMENT ~ 3-5 YEARS LIFETIME**
  - o **Cooling Sensor Arrays to Tens of Kelvin**
  - o **Cooling Sensor Arrays to Millikelvin  $<T < 100k$**

### **COMMUNICATIONS IMPORTANCE**

- o **MISSION TO PLANET EARTH**
  - Optical (> 500 Mbps) GEOPLAT/GEOPLAT Links
  - GEOPLAT/EOS Links
  - Coherent Links [Two or More Platforms Employed as a Single Observational Instrument]
  - Optical Link Direct to Ground
- o **MARS EXPLORATION**
  - Mars Rover (Eliminate Large Antenna)
  - Manned Missions
- o **LUNAR BASE**
  - LaGrange Point / Earth -GEO / Far Side Optical Link
- o **OTHER MISSIONS**
  - Enables Star Probe (Communication in and Thru Sun's Plasma)
  - TAU (Thousand Astronomical Unit)
  - Planetary - High Data Rate

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

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6.3 Information Systems

***In-Space Experiments Information Systems Critical Technology Requirements***

Martin M. Sokoloski / John Dalton  
NASA Headquarters / NASA Goddard Space Flight Center

**COMMUNICATIONS TECHNOLOGY NEEDS**

- o **EXPERIMENTAL TEST DATA ON OPTO-THERMO-STRUCTURAL MECHANICAL INTERACTIONS OF SPACE-BASED "OPTICAL BENCH" FOR OPTICAL COMMUNICATIONS**
  - **Laser Power & Cooling**
  - **Acquisition (Closed & Open Loop)**
  - **Pointing and Tracking**
  - **Communications Links**
  - **Very Large Baselines (> 40,000 Km)**

**COMMUNICATIONS IN-SPACE TESTING REQUIRED**

- o **Obtain Experimental Test Data to Obtain and Validate Complex Analytical Models to Enable Overall Laser Communications Systems Optimization**
- o **The In-Space Environment:**
  - **Platform Vibration**
  - **Thermal Distortion**
  - **Radiation**
  - **Natural Background Sources**
  - **S/C Glow**
  - **Long Baselines**

Theme 6 of 8

**SENSORS AND INFORMATION SYSTEMS**

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6.3 Information Systems

***In-Space Experiments Information Systems Critical Technology Requirements***

**Martin M. Sokoloski / John Dalton**  
NASA Headquarters / NASA Goddard Space Flight Center

**INFORMATION SYSTEMS TECHNOLOGY NEEDS**

- o **Intelligent Information Systems to Support Automated Operations, On-Board Processing, & Robotics**
  - **Special Purpose Processors: Image, Symbolic, Neural Network**
  - **High Performance General Purpose Processors**
  - **High Volume Storage**

**IMPORTANCE**

- o **MISSION TO EARTH:**
  - **On-Board Feature Extraction & Processing Required to Reduce Large Volume of Global Monitoring Data and Enable Manageable Communications and Ground Processing Costs**
- o **MICROGRAVITY:**
  - **On-Board Selection of Features of Interest From High Rate/Volume Image Sequences. Required to Meet TDRS Communication Limit**
- o **PLANETARY ROVERS:**
  - **On-Board Science Analysis & Autonomous Vehicle Operation**

**IN-SPACE TESTING REQUIRED**

- o **System-Level Validation:**
  - **Adaptive Response to Real-Time Observations**
  - **Performance and Reliability in Space Radiation Environment**
- o **Space Environment Testing**
  - **Space-Borne VHSIC Multiprocessor System**
  - **CSTI High Rate Data Systems**

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**SENSORS AND INFORMATION SYSTEMS**

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6.3 Information Systems

***In-Space Experiments Information Systems Critical Technology Requirements***

Martin M. Sokoloski / John Dalton  
NASA Headquarters / NASA Goddard Space Flight Center

**INFORMATION SYSTEMS IN-SPACE TECHNOLOGY  
NEEDS**

- o Space Qualified Components with Performance Comparable to Ground System Capability
- o Confidence Testing of Commercial-Grade Components to Provide Low-Cost, Low-Risk Applications
- o Zero-G Testing of Storage Systems

**IMPORTANCE:**

- o Reduce Cost of Space Experiments
- o Modular, Standard Processing Elements for Multi-Mission Applications
- o Mission Enabling for Some Applications (Eg. On-Board Instrument Calibration, Automation of Operations)

**IN-SPACE TESTING REQUIRED:**

- o Laboratory for On-Going Testing of New Components
  - Shuttle/SSF Low Inclination Orbit
  - Polar & Geo Radiation Environment
- o Build on CRRES Experience
- o Improve Model of Radiation Environmental Effects
- o Incorporate as Last Step of Ground Modeling & Testing Process

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**SENSORS AND INFORMATION SYSTEMS**

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6.3 Information Systems

***In-Space Experiments Information Systems Critical Technology Requirements***

**Martin M. Sokoloski / John Dalton**  
NASA Headquarters / NASA Goddard Space Flight Center

**SENSORS & INFORMATION SYSTEMS IN-SPACE  
TECHNOLOGY NEEDS**

**SENSORS**

- o Precision Pointing, Control, and Stabilization
- o Coolers

**COMMUNICATIONS**

- o High Rate Optical Communications
- o Closed and Open Loop Acquisition
- o Pointing and Tracking

**INFORMATION SYSTEMS**

- o Intelligent Systems For In-Space Observations, Automated Control, and Robotics
- o Effective Space Application of Processor and Storage Technology Advances

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## IN-SPACE SYSTEMS

Theme 7 of 8

Background and Objectives

### *Theme Session Objectives and Prioritization Criteria*

Jon B. Haussler  
NASA Marshall Space Flight Center

#### • PURPOSE

- IDENTIFY & PRIORITIZE IN-SPACE TECHNOLOGIES  
FOR EACH THEME WHICH:
  - ARE CRITICAL FOR FUTURE NATIONAL SPACE PROGRAMS
  - REQUIRE DEVELOPMENT & IN-SPACE VALIDATION
- OBTAIN AEROSPACE COMMUNITY COMMENTS & SUGGESTIONS ON  
OAST IN-STEP PLANS

#### • PRODUCT

- AEROSPACE COMMUNITY RECOMMENDED  
PRIORITY LISTING OF CRITICAL SPACE TECHNOLOGY  
NEEDS & ASSOCIATED SPACE FLIGHT EXPERIMENTS

## IN-SPACE SYSTEMS

### THEME ELEMENTS (SUBTHEMES)

MATERIAL PROCESSING

MAINTENANCE, REPAIR AND FIRE SAFETY

PAYLOAD OPERATIONS

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## IN-SPACE SYSTEMS

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Background and Objectives

### *Theme Session Objectives and Prioritization Criteria*

Jon B. Haussler  
NASA Marshall Space Flight Center

## 1985 WORKSHOP THEME

### IN-SPACE OPERATIONS

- **ADVANCED LIFE SUPPORT SYSTEM**
- **BIOMEDICAL RESEARCH**
- **TETHERS**
- **MAINTENANCE AND REPAIR**
- **ORBITAL TRANSFER VEHICLE**
- **SYSTEM TESTING**
- **PROPULSION**
- **MATERIAL PROCESSING**

## THEME SESSION AGENDA

### **• THEME ELEMENT SESSIONS**

- **CRITICAL SPACE TECHNOLOGY NEEDS FOR THEME ELEMENT.**

#### **FROM PERSPECTIVE OF:**

- **INDUSTRY, UNIVERSITIES & GOVERNMENT**

(BRIEF PRESENTATIONS OF MAJOR TECHNICAL PROBLEMS/CONCERNS/NEEDS IN THIS THEME ELEMENT AREA FROM THE PERSPECTIVE OF THE SPEAKER'S ORGANIZATION)

- **OPEN DISCUSSION WITH THE AUDIENCE & THEME ELEMENT**

#### **SPEAKERS/THEME LEADER**

- **QUESTION & ANSWER WITH SPEAKERS**
- **IDENTIFICATION OF ADDITIONAL TECHNOLOGIES FROM AUDIENCE**

- **AUDIENCE PRIORITIZATION OF CRITICAL TECHNOLOGIES**

(INCLUDING THOSE TECHNOLOGIES DISCUSSED BY THE AUDIENCE)

(NOTE: AUDIENCE SHOULD USE PRIORITIZATION CRITERIA PRESENTED ON VIEWGRAPH)

### **• COMBINATION & PRIORITIZATION OF THEME TECHNOLOGIES**

- **DISCUSSION BETWEEN AUDIENCE AND ALL THEME ELEMENT SPEAKERS**
- **RESOLUTION OF CRITICAL TECHNOLOGIES ACROSS THEME**

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**IN-SPACE SYSTEMS**

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Background and Objectives

***Theme Session Objectives and Prioritization Criteria***

Jon B. Haussler  
NASA Marshall Space Flight Center

**MATERIAL PROCESSING SPEAKERS**

- **DR. ROBERT J. NAUMANN, MSFC**
- **DR. DAVID W. SAMMONS, UNIVERSITY OF ARIZONA**
- **DR. JOHN T. VIOLA, ROCKWELL INTERNATIONAL**

**MAINTENANCE AND REPAIR SPEAKERS**

- **MR. ED FALKENHAYN, GSFC**
- **MR. BOB  
DELLACAMERA, McDONNELL DOUGLAS**

**FIRE SAFETY SPEAKER**

- **MR. WALLACE W. YOUNGBLOOD, WYLE LABORATORIES**

**PAYLOAD OPERATIONS SPEAKERS**

- **DR. JEFFREY A. HOFFMAN, JSC**
- **PROF. GEORGE MORGENTHALER, UNIVERSITY OF COLORADO**
- **MR. LEE LUNSFORD, LOCKHEED**

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## IN-SPACE SYSTEMS

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Background and Objectives

### *Theme Session Objectives and Prioritization Criteria*

Jon B. Haussler  
NASA Marshall Space Flight Center

## PRIORITIZATION CRITERIA\*

### 1. CRITICAL ENABLING TECHNOLOGIES

- TECHNOLOGIES WHICH ARE CRITICAL FOR FUTURE U.S. SPACE MISSIONS

### 2. COST REDUCTION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN DECREASE COSTS OR COMPLEXITY  
(E.G., DEVELOPMENT, LIFE-CYCLE, OPERATIONS)

### 3. BROAD APPLICATION TECHNOLOGIES

- TECHNOLOGIES WHICH CAN IMPROVE OR ENHANCE A VARIETY OF SPACE MISSIONS

### 4. REQUIRE IN-SPACE VALIDATION

- TECHNOLOGIES WHICH REQUIRE THE SPACE ENVIRONMENT OR MICRO-GRAVITY FOR  
VALIDATION OR EXPERIMENTATION

\* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1. = HIGHEST)

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## IN-SPACE SYSTEMS

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### 7.1 Materials Processing

#### *Materials Processing*

Larry Spencer

NASA Headquarters, Microgravity Science and Applications Division

## WHY MICROGRAVITY?

- **ELIMINATE BUOYANCY-DRIVEN CONVECTION**

ESTABLISH DIFFUSION-CONTROLLED CONDITIONS  
VASTLY SIMPLIFIES TRANSPORT ANALYSIS  
SUPPRESSES THERMAL AND COMPOSITION FLUCTUATIONS  
ELIMINATES UNWANTED MIXING  
UNMASKS OTHER, MORE SUBTLE FLOWS

- **ELIMINATE SEDIMENTATION**

MAINTAIN HETEROGENEOUS MIXTURES OR SUSPENSIONS  
PREVENT UNWANTED PHASE SEPARATION  
INVESTIGATE SECOND-ORDER FORCES ON PARTICLES OR DROPLETS  
OBJECTS CAN BE FREE-FLOATED

- **ELIMINATE HYDROSTATIC PRESSURE**

LIQUID CAN BE CONSTRAINED BY THEIR SURFACE TENSION  
DEPLOY LIQUID BRIDGES TO RAYLEIGH LIMIT  
EXTEND FLOAT ZONE PROCESS TO LOW SURFACE TENSION MATERIALS  
ELIMINATE PRESSURE VARIATIONS IN CRITICAL POINT EXPERIMENTS

### **BONUSES**

ULTRAHIGH VACUUM —  $\sim 10^{-14}$  TORR BEHIND WAKE-SHIELD  
HIGH PUMPING SPEED — VIRTUALLY INFINITE SINK  
HIGH HEAT REJECTION —  $\sim 4K$  RADIATION BACKGROUND  
FLUX OF ATOMIC OXYGEN — COLLIMATED BEAM OF 5 eV 0 ATOMS  
UNFILTERED SUNLIGHT — SOURCE OF V.U.V. ESPECIALLY 121.6 nm.

## GOALS

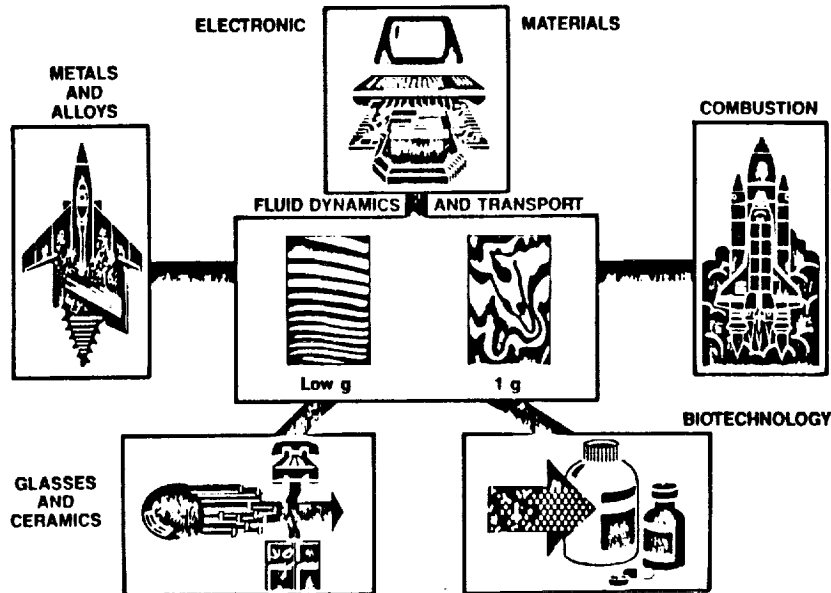
- o USE THE MICROGRAVITY ENVIRONMENT AS A LABORATORY TO:
  - 1) OBTAIN UNDERSTANDING OF BASIC PHYSICAL PHENOMENA AND PROCESSES
  - 2) QUANTIFY LIMITATIONS/EFFECTS IMPOSED BY GRAVITY ON THESE PHENOMENA AND PROCESSES
  - 3) APPLY THIS BASIC KNOWLEDGE TO BOTH EARTH BASED AND SPACE BASED PROCESSES OR PRODUCTS
- o DISSEMINATE THE RESEARCH DATA BASE TO THE U.S. PRIVATE SECTOR TO ENHANCE U.S. COMPETITIVENESS IN THE WORLD MARKET

Theme 7 of 8

**IN-SPACE SYSTEMS**  
7.1 Materials Processing  
*Materials Processing*

Theme 7 of 8

Larry Spencer  
NASA Headquarters, Microgravity Science and Applications Division



**MICROGRAVITY SCIENCE AND  
APPLICATIONS DISCIPLINES**

**FLUID DYNAMICS AND  
TRANSPORT PHENOMENA**

- CRITICAL POINT PHENOMENA
- SURFACE BEHAVIOR
- CHEMICAL REACTION
- RELATIVITY
- TRANSPORT PHENOMENA
- SOLIDIFICATION MODELS

**GLASSES AND CERAMICS**

- NEW GLASS COMPOSITIONS
- FINING
- SPHERICAL SHELLS
- NUCLEATION/CRYSTALLIZATION

**ELECTRONIC MATERIALS**

- VAPOR GROWTH
- MELT GROWTH
- SOLUTION GROWTH
- FLOAT ZONE

**METALS AND ALLOYS**

- MONOTECTICS
- EUTECTICS
- UNDERCOOLING
- SOLIDIFICATION FUNDAMENTALS
- THERMOPHYSICAL PROPERTIES

**BIOTECHNOLOGY**

- NEW TECHNIQUE DEVELOPMENT
- EVALUATION OF CFES
- PROTEIN CRYSTAL GROWTH
- BIOREACTOR

**COMBUSTION SCIENCE**

- SOLID SURFACE
- POOL BURNING
- PARTICLE CLOUD
- DROPLET BURNING

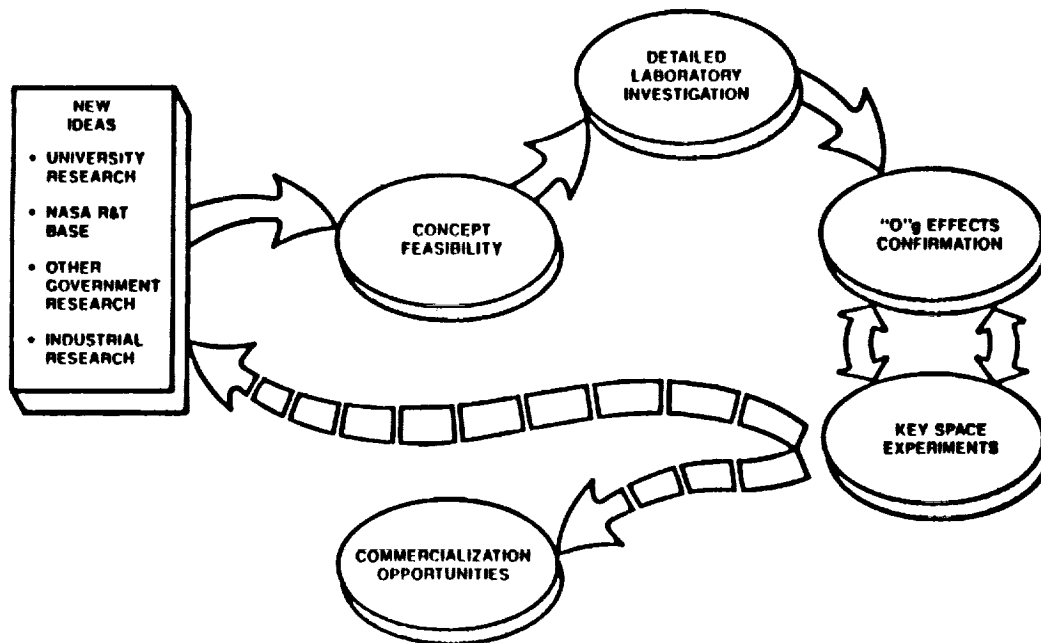
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**IN-SPACE SYSTEMS**  
7.1 Materials Processing  
*Materials Processing*

Theme 7 of 8

Larry Spencer  
NASA Headquarters, Microgravity Science and Applications Division

**THE APPROACH**



**MICROGRAVITY SCIENCE AND APPLICATIONS  
TECHNOLOGY DEVELOPMENT**

- VIBRATION ISOLATION SYSTEMS ( $10^{-8}g$ ,  $10^{-3}Hz$ )
- REACTIONLESS ROBOTICS
- ADVANCED HIGH-TEMPERATURE FURNACES
- HIGH-TEMPERATURE MATERIALS FOR FURNACES (3000°C)
- HIGH-FRAME RATE/HIGH-RESOLUTION VIDEO (100 microns, 1000 FPS)
- CRYSTAL GROWTH NUCLEATION DETECTION (10Å)
- NON-CONTACT TEMPERATURE MEASUREMENT CAPABILITY (5°K TO 2500°K)
- ELECTRONIC CRYSTAL GROWTH MEASUREMENT TECHNOLOGY
- FLUID AND COMBUSTION DIAGNOSTICS
- ACCELERATION MEASUREMENT ( $10^{-8}g$ )

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**IN-SPACE SYSTEMS**

Theme 7 of 8

7.1 Materials Processing

***Materials Processing***

Larry Spencer

NASA Headquarters, Microgravity Science and Applications Division

**IN-SPACE TECHNOLOGY VALIDATION NEEDS**

- **CHARACTERIZATION, MEASUREMENT, AND CONTROL OF THE MICROGRAVITY ENVIRONMENT**
- **ULTRAHIGH VACUUM TECHNOLOGY**
- **MEASUREMENT AND CONTROL OF FLUIDS**
- **REACTIONLESS ROBOTICS**
- **IN-SPACE SAMPLE PREPARATION AND ANALYSIS**
- **HANDLING OF MATERIALS AND WASTE PRODUCTS**
- **COMBUSTION DIAGNOSTIC TECHNOLOGY**

Theme 7 of 8

**IN-SPACE SYSTEMS**

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7.1 Materials Processing

***Floating-Zone Crystal Growth in Space***

John T. Viola  
Rockwell International Science Center

**INTRODUCTION / BACKGROUND**

- O ELECTRONIC COMPONENTS AND SUBSYSTEMS FOR DEFENSE AND COMMERCIAL APPLICATIONS  
IN DEVELOPMENT
  - GaAs SIGNAL PROCESSORS, INFRARED FOCAL PLANE ARRAYS, NON-LINEAR  
OPTICS AND PHOTONICS
- O HIGH QUALITY, DEFECT-FREE MATERIAL IS NEEDED FOR THESE APPLICATIONS
- O CURRENT TECHNOLOGY LIMITS SINGLE CRYSTAL SIZE AND IMPOSES UNWANTED DEFECT  
CONCENTRATIONS (TWINS, DISLOCATIONS, PRECIPITATES, GRAIN BOUNDARIES)
- O FLOAT ZONE CRYSTAL GROWTH IN MICROGRAVITY CAN YIELD LARGER CRYSTALS WITH  
LOWER DEFECT CONCENTRATIONS.
  - O REDUCED CONTAMINANT CONCENTRATION AND SPURIOUS NUCLEATION BY ELIMINATION  
OF INTERACTION WITH AN AMPOULE
  - O LARGER DIAMETER ZONE IS POSSIBLE SINCE SURFACE TENSION NEED NOT SUPPORT  
THE WEIGHT OF THE MELTED ZONE
  - O ELIMINATION OF PLASTIC DEFORMATION FROM CRYSTAL'S OWN WEIGHT.
- O FLOAT ZONE EXPERIMENTS IN SPACE ARE NEEDED TO DEMONSTRATE FEASIBILITY

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**IN-SPACE SYSTEMS**

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**7.1 Materials Processing**

***Floating-Zone Crystal Growth in Space***

**John T. Viola**

Rockwell International Science Center

**TECHNOLOGY NEEDS**

- 0 EXPERIMENTAL FACILITY NEEDED TO PERFORM CONTROLLED CRYSTAL GROWTH OF HIGH MELTING ELECTRONIC MATERIALS WITH HIGH CONSTITUENT VAPOR PRESSURES.

REQUIREMENT

PURPOSE

SAMPLE SUPPORT AND CHANGEOUT

CONTACTLESS PROCESSING; MULTIPLE EXPERIMENTS

FURNACE TEMPERATURES UP TO 1500C

ELECTRONIC MATERIALS OF INTEREST

HOT WALL FURNACE

ELIMINATE VAPOR LOSS BY CONDENSATION

VARIABLE SPEED ZONE HEATER

ESTABLISH AND MOVE MOLTEN ZONE

POWER BUDGET MANAGEMENT

ESTABLISH AND MAINTAIN PROPER

TEMPERATURE PROFILE

MOLTEN ZONE DIMENSIONAL SENSING

OPTIMIZE CRYSTAL GROWTH CONDITIONS

(LENGTH, SOLID-LIQUID INTERFACES

FLUID FLOWS)

REQUIREMENT

PURPOSE

FURNACE AND GROWTH SYSTEM TEMPERATURE

OPTIMIZE CRYSTAL GROWTH CONDITIONS

SENSING

CONTROLLABLE POWER AND POSITIONAL

ESTABLISH AND MAINTAIN PROPER

SETTINGS

TEMPERATURE PROFILE

EVENTUAL EXPERT SYSTEM CONTROL

AUTONOMOUS OPERATION

PROBE FOR IN SITU OBSERVATION OF

EXPERT SYSTEM CONTROL OF GROWTH PROCESS

GROWING CRYSTAL QUALITY

(ULTRASOUND?)

ROBOTIC MANIPULATION

AUTONOMOUS OPERATION/TELESCIENCE

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.1 Materials Processing**

***Floating-Zone Crystal Growth in Space***

**John T. Viola**

Rockwell International Science Center

**IN-SPACE EXPERIMENTATION NEEDS / VOIDS**

- 0 FLOATING-ZONE CRYSTAL GROWTH OF HIGH-MELTING SEMICONDUCTOR COMPOUNDS TO DEMONSTRATE LARGE SIZE, HIGH PURITY, LOW DEFECT, SINGLE CRYSTAL MATERIAL.
- 0 "CONTAINERLESS" PROCESSING TO DEMONSTRATE ADVANTAGES OF CONTACTLESS CRYSTAL GROWTH.
- 0 SENSING AND IMAGING SYSTEM FOR FLOATING-ZONE CRYSTAL GROWTH TO DEMONSTRATE CONTROL OF MOLTEN ZONE SIZE, LENGTH, SHAPE AND RELATIVE MOTION AND FLOW.
- 0 EXPERIMENTS TO INVESTIGATE FLUID DYNAMIC PHENOMENA, SUCH AS THERMOCAPILLARY FLOW, THAT ARE OF CRITICAL IMPORTANCE IN EARTH-BASED PROCESSES, BUT CANNOT BE STUDIED ON EARTH BECAUSE OF GRAVITATIONAL EFFECTS; RESULTS CAN BE APPLIED IN BOTH EARTH AND SPACE-BASED PROCESSES.

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.1 Materials Processing

#### *Materials Processing — Cells and Cellular Products*

David W. Sammons  
University of Arizona

## INTRODUCTION / BACKGROUND

**EXPERIMENTS WITH CELLS UNDER MICROGRAVITY ARE  
IMPORTANT TO:**

- O BASIC SCIENCE**
- O COMMERCIALIZATION OF BIOTECHNOLOGY**
- O SPACE MEDICINE AND HUMAN ADAPTATION**
- O TRANSFER OF SPACE TECHNOLOGY TO  
TERRESTRIAL APPLICATIONS**

## TECHNOLOGY NEEDS

- O HARDWARE FOR CELL MAINTENANCE & GROWTH**
- O HARDWARE FOR PROLONGED CELL STORAGE  
AND ACTIVATION**
- O VISION SYSTEMS FOR COUNTING, MEASURING  
AND EVALUATING CELLS**
- O AUTOMATED FLUID TRANSFER SYSTEMS THAT  
MAINTAIN STERILE ENVIRONMENTS**
- O SEPARATION SYSTEMS UTILIZING CELLULAR &  
BIOPHYSICAL CHARACTERISTICS OF TARGET CELLS**
- O ANALYSIS & QUALITY CONTROL INSTRUMENTATION**
- O TELECOMMUNICATION & EXPERT SYSTEMS TO  
MONITOR & ADJUST IN-SPACE EXPERIMENTATION**
- O MAINTENANCE & CONTINUED GROWTH INSTRUMENTATION  
FOR NEW IN-SPACE GENERATED PRODUCTS**
- O RECOVERY AND ANALYSIS SYSTEMS OF IN-SPACE  
GENERATED CELL PRODUCTS**

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.1 Materials Processing**

***Materials Processing — Cells and Cellular Products***

David W. Sammons  
University of Arizona

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**SAMPLE PREPARATION AND PROCESSING**

- O SAMPLE INJECTION**
- O LIQUID MIXING DEVICES**

**MAINTENANCE AND/OR CULTURE**

- O GAS & TEMPERATURE CONTROLLED INCUBATORS**

**SEPARATION OF CELLS (POPULATION & SINGLE)**

- O ELECTROKINETIC**
- O CELL SORTING**
- O AFFINITY**

**TRANSFER OF FLUIDS & CELLS INTO REACTOR AND OUT OF REACTOR**

- O VALVING**
- O PUMPING OF FLUIDS**

**REACTION CHAMBERS**

- O ELECTROFUSION/ELECTROPERMEATION**
- O CELL ACTIVATION**
- O HOLDING TANKS FOR SECRETION OF PRODUCTS**

**IN-LINE SEPARATION OF CELLS AND PRODUCTS**

- O ELECTROKINETIC**
- O CELL SORTING**
- O AFFINITY**

**RECYCLE UNREACTED CELLS TO MAINTENANCE AND/OR CULTURE**

- O VALVING**
- O PUMPING OF FLUIDS**

**SPECIALIZED CLONING AND GROWTH CHAMBERS**

- O AUTOMATIC DILUTORS**
- O GELS AND SPECIAL GROWTH CHAMBERS**

**ANALYSIS OF CLONES & ESTIMATION OF YIELDS**

- O COLORIMETRIC, FLUOREMETRIC & RADIOACTIVE**

**RECOVERY OF CELL PRODUCT FOR RETURN OR FURTHER PROCESSING**

- O INCUBATORS**
- O AFFINITY RESIN MATERIALS OF HIGH CAPACITY**

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.2 Maintenance, Repair, and Fire Safety *Maintenance, Servicing and Repair in Space*

Ed Falkenhayn  
NASA Goddard Space Flight Center, Satellite Servicing Project

#### INTRODUCTION/BACKGROUND

##### CURRENT/PLANNED MAINTENANCE & REPAIR CAPABILITY

- O PAYLOADS PLANNING ON STS, SPACE STATION OR OMV DOCKING WILL DOCK TO FSS THREE LATCH BERTHING RING
- O FSS BERTHING RING PROVIDES ELECTRICAL UMBILICAL SERVICES:
  - POWER
  - DATA
  - COMMAND
- O FSS BERTHING RING PROVIDES MECHANICAL POSITIONING
  - PIVOTS 0 TO 90°
  - ROTATION  $\pm 175^\circ$

#### OPERATIONS/FUNCTIONS

- O POSITIONING FOR INSPECTION AND EASE OF ACCESS
- O TOTAL OR SELECTIVE POWER-OFF TO PERMIT REPAIR AND/OR MODULE EXCHANGES
- O INDEPENDENT HEATER POWER TO MAINTAIN THERMAL LIMITS ON COMPONENTS/INSTRUMENTS/SYSTEMS
- O COMMAND & TELEMETRY LINKS PERMIT SPACECRAFT/PAYLOAD CHECKOUT
  - FROM ORBITER AFT FLIGHT DECK
  - FROM USER'S POCC VIA ORBITER AVIONICS
- O AFTER SMM REPAIR IN 1984, DURING NIGHT, BETWEEN REPAIR DAY & RELAUNCH DAY, FULL SPACECRAFT FUNCTIONAL CHECK WAS PERFORMED

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

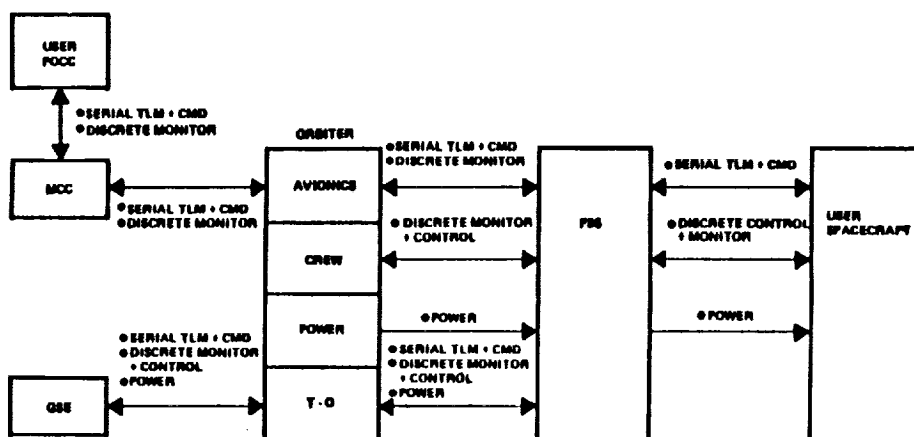
### 7.2 Maintenance, Repair, and Fire Safety

#### *Maintenance, Servicing and Repair in Space*

Ed Falkenhayn

NASA Goddard Space Flight Center, Satellite Servicing Project

## FSS ELECTRICAL AND AVIONICS SERVICES



## DIAGNOSTIC SYSTEMS

### THE ON-BOARD COMPUTER - NSSC-1

- ON-BOARD MANAGEMENT, AND UPDATING OF SPACECRAFT PERFORMANCE STATISTICS & TREND DATA
- AUTOMATIC RESPONSES TO PREDEFINED SPACECRAFT ANOMALIES/HARDWARE FAILURES SAFE HOLD
- ALLOWS IN-FLIGHT TELEMETRY FORMAT MODIFICATIONS FOR DIAGNOSTICS AND RECONFIGURATION FOR OPTIMUM SCIENCE RETURN AS HARDWARE/INSTRUMENTS AGE AND DEGRADE

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

7.2 Maintenance, Repair, and Fire Safety  
***Maintenance, Servicing and Repair in Space***

**Ed Falkenhayn**  
NASA Goddard Space Flight Center, Satellite Servicing Project

**REMOTE SERVICING - THE NEXT STEP**

MANY SPACECRAFT OPERATE BEYOND STS/OMV AND SPACE STATION/OMV ALTITUDE AND INCLINATION

REMOTE SERVICING WILL USE ELV LAUNCHED SERVICING OPERATIONS; ENGINEERING STUDIES NEED TO ADDRESS:

- O INVESTMENT IN ELV LAUNCHED, EXPENDABLE SERVICER CAPABILITY
- O PROGRAMMATICS/LOGISTICS/ECONOMICS OF A SPACE BASED SERVICING FACILITY
- O SERVICER/SPACECRAFT INTERDEPENDENCY; SHUT DOWN/TRANSFER OF SPACECRAFT FUNCTIONS
- O MANIPULATOR SYSTEM REQUIREMENTS/CAPABILITIES
- O TELEOPERATOR VS SUPERVISED AUTONOMOUS VS AUTONOMOUS OPERATIONS

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.2 Maintenance, Repair, and Fire Safety**

***Spacecraft Fire Safety for Advanced Spacecraft***

Wallace W. Youngblood  
Wyle Laboratories

**BACKGROUND**

- EARLY SPACECRAFT (MERCURY THROUGH APOLLO) UTILIZED  
A PURE OXYGEN ATMOSPHERE AT 5 PSIA
- SKYLAB UTILIZED AN ATMOSPHERE OF 65% OXYGEN,  
35% NITROGEN AT 5.2 PSIA
- STS SHUTTLE & SPACELAB ADOPTED A SEA LEVEL AIR ATMOSPHERE
- FIRE DETECTORS (UV SENSORS) FIRST USED ON SKYLAB
- A PORTABLE FOAM FIRE EXTINGUISHER WAS PROVIDED ON  
THE APOLLO CSM
- FIXED AND PORTABLE HALON 1301 EXTINGUISHANT SYSTEMS  
ADOPTED FOR STS SHUTTLE
- DESIGN IS NOT FIRM FOR SPACE STATION
- ALL ASPECTS OF SPACECRAFT FIRE SAFETY MUST BE REVISITED:
  - MATERIAL SELECTION/CONFIGURATIONS
  - MATERIAL FLAMMABILITY/FLAME SPREAD
  - FIRE DETECTION/SUPPRESSION
  - HUMAN EFFECTS
  - ATMOSPHERES (NOMINAL/OFF-NOMINAL)

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

7.2 Maintenance, Repair, and Fire Safety  
***Spacecraft Fire Safety for Advanced Spacecraft***

Wallace W. Youngblood  
Wyle Laboratories

**TECHNOLOGY NEEDS**

**DATA BASE NEEDS FOR LOW GRAVITY IGNITION/FLAME SPREAD:**

- CRITICAL HEAT FLUX REQUIRED FOR IGNITION
- EFFECT OF RADIATION ENVIRONMENT
- FLAME SPREAD RATE AND EXTINCTION LIMITS
- FLAME CHARACTERISTICS: FLAME SHAPE, TEMPERATURE AND COLOR; RADIANT ENERGY; SOOT GENERATION

**UPGRADED MATERIAL FLAMMABILITY STANDARDS:**

- EXPANDED DATA BASE NEEDED FOR MATERIAL IGNITION AND FLAME SPREAD IN LOW GRAVITY
- STANDARDS NEEDED FOR CONFIGURATION MODELING
- DEVELOPMENT OF CORRELATIONS FOR LOW GRAVITY FLAMMABILITY
- UNIFORM FLAMMABILITY TESTS FOR NASA, ESA, NASD...

**FIRE DETECTION DEVICE NEEDS:**

- FIRE DETECTION IS REQUIRED AT EARLIEST STAGE OF EVENT
- RAPID RESPONSE OVERHEAT AND INCIPIENT CONDITION DETECTORS
- LOW-GRAVITY DATA BASE NEEDS:
  - FLAME CHARACTERISTICS
  - SMOKE PARTICLE SIZE AND SIZE DISTRIBUTION
  - DETECTABLE AEROSOLS DUE TO OVERHEAT
- MEANS FOR MINIMIZATION OF FALSE ALARMS:
  - EXPERT SYSTEMS REQUIRED
  - SPECIAL SYSTEMS FOR CREW ALERTING
  - ARTIFICIAL FIRE SIGNATURE GENERATORS

**FIRE EXTINGUISHANTS AND SYSTEMS:**

- MUST BE COMPATIBLE WITH SPACECRAFT SYSTEMS
- MUST BE EFFECTIVE ON ALL FIRE SCENARIOS INCLUDING HYPERBARIC REGIONS
- DATA BASE REQUIRED FOR EXTINGUISHANT USE:
  - SEVERITY OF TOXIC PRODUCTS RESULTING FROM VARIOUS FIRE INTERACTION SCENARIOS
  - EFFECTIVENESS OF EXTINGUISHANTS VERSUS FLAME TEMPERATURE AND OXYGEN CONCENTRATION

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.2 Maintenance, Repair, and Fire Safety

#### *Spacecraft Fire Safety for Advanced Spacecraft*

Wallace W. Youngblood  
Wyle Laboratories

#### IN-SPACE EXPERIMENTATION NEEDS

##### LOW-GRAVITY IGNITION AND FLAME SPREAD:

- INVESTIGATE MATERIAL IGNITABILITY
- FOR SELECTED MATERIALS, DETERMINE FLAME SPREAD RATES AND EXTINCTION LIMITS FOR VARIOUS ENVIRONMENTS
- ASSESS POTENTIAL HAZARD FOR SPONTANEOUS COMBUSTION OF PARTICLE CLOUDS
- ASSESS FIRE HAZARDS ASSOCIATED WITH FLAMMABLE LIQUID SPILLS

##### FIRE DETECTION IN LOW GRAVITY:

- DEVELOP A DATA BASE OF FIRE SIGNATURES IN LOW GRAVITY:
  - INVESTIGATE FLAME CHARACTERISTICS
  - EVALUATE LOW-GRAVITY EFFECTS ON SMOKE PRODUCTION
- TEST NEW DETECTORS IN LOW-GRAVITY USING REAL AND ARTIFICIAL FIRE SIGNATURES

##### FIRE EXTINGUISHMENT:

- INVESTIGATE EFFECTIVENESS IN LOW-GRAVITY
  - ASSESS EFFECTIVENESS/HAZARD WHEN USED IN HYPERBARIC REGIONS
  - SAFE FOR CREW AND COMPATIBLE WITH SYSTEMS?
- ESTABLISH DATA BASE FOR FIRE/EXTINGUISHANT INTERACTION
  - MAP EXTINGUISHANT EFFECTIVENESS VERSUS FLAME TEMPERATURE
  - EVALUATE EFFECTIVENESS ON SMOLDERING COMBUSTION

##### POST-FIRE CLEANUP:

- DEVELOP MEANS FOR EFFECTIVE PICK UP OF SMOKE PARTICLES AND AEROSOLS REMAINING AFTER AN EVENT
- EVALUATE EFFECTS OF COMBUSTION/EXTINGUISHANT PRODUCTS ON ELECTRONIC GEAR

##### FIRE SAFETY EXPERIMENT CONCEPTS:

- EXPERIMENTS GENERALLY NEED TO BE COMPACT/MULTI-PURPOSE
- ATTEMPT TO MAXIMIZE DATA OBTAINED
- PLAN TO ATTEND NASA LEWIS SPONSORED WORKSHOP:
  - INTERNATIONAL MICROGRAVITY COMBUSTION WORKSHOP
  - DATE: JANUARY 25 & 26, 1989

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.2 Maintenance, Repair, and Fire Safety *Maintenance, Servicing and Repair in Space*

Bob Dellacamera  
McDonnell Douglas Space Systems Company

## INTRODUCTION/BACKGROUND

- MAINTENANCE, SERVICING & REPAIR HAS BEEN DONE IN SPACE
- MANNED MAINTENANCE & REPAIR SO FAR
- EXTREMELY PLANNED OR UNPLANNED
- NOT NORMALLY BASELINED

## MISSION APPLICATIONS

- ALL MISSIONS CAN BENEFIT FROM INCLUDING MAINTENANCE SERVICING AND REPAIR PROVISIONS
  - SOFTWARE
  - HARDWARE
  - REPLENISHMENT
- EVA IS NOT THE ONLY THE ONLY METHOD OF MAINTENANCE, SERVICING & REPAIR
- MAINTENANCE, SERVICING & REPAIR REQUIRES A SUPPORT INFRASTRUCTURE FOR FULL IMPLEMENTATION

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.2 Maintenance, Repair, and Fire Safety

#### *Maintenance, Servicing and Repair in Space*

**Bob Dellacamera**

McDonnell Douglas Space Systems Company

## TECHNOLOGY NEEDS

### DEVELOP TECHNOLOGIES FOR SUPPORTING INFRASTRUCTURE

- ROBOTICS
  - COGNITIVE CAPABILITIES
  - SERVICE ROBOTS
- EVA SUITS
  - SPACE BASING
  - MORE HARDNESS
  - LESS MAINTENANCE
- COMPOSITE REPAIR
  - TRUSS
  - PRESSURE SHELLS
- CONSUMMABLES
  - CRYO PUMPING
  - CRYO STORAGE
    - \* INSULATION
    - \* RELIQUIFACTION
  - TOXIC FLUIDS
  - DECONTAMINATE THE REFUELER
- TECHNICAL DATA
  - FORMAT/ACCESS
  - PRESENTATION/STORAGE
  - UPDATES

## IN-SPACE EXPERIMENT NEEDS/VOIDS

- INSTITUTIONALIZE MAINTENANCE, SERVICING & REPAIR BY DEMONSTRATION
  - MANNED                      -ROBOTIC
  - COMBINATION
- MAINTAIN, SERVICE & REPAIR AT HIGH INCLINATION AND POLAR ORBITS
- DEMONSTRATE MAINTENANCE, SERVICING & REPAIR HARDWARE FOR:
  - REFUELING
  - SELF-CONTROLLED ROBOTS
  - MANNED POLAR OPERATIONS

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.2 Maintenance, Repair, and Fire Safety *Maintenance, Servicing and Repair in Space*

Bob Dellacamera  
McDonnell Douglas Space Systems Company

## IN-SPACE EXPERIMENT RECOMMENDATION

- ALL SPACE SYSTEMS SHOULD DEMONSTRATE MAINTENANCE, SERVICING & REPAIR CONCEPTS AS PART OF DEVELOPING THE BASIC MISSION CONCEPT
- APPLY ROBOTICS TO MAINTENANCE, SERVICING & REPAIR PROBLEMS SOON
- MAINTAIN AND REPAIR A ROBOTIC SERVICER ON-ORBIT
- FLY A PROTOTYPE HARD SUIT AT HIGH INCLINATIONS
- DEVELOP A SMALL-SCALE LONG DURATION REFUELING PILOT PLANT(CRYO,STORABLE)
- REFUEL SPACECRAFT ON-ORBIT

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.3 Payload Operations

#### *Payload Operations from the Perspective of Manned Space Flight*

Dr. Jeffrey A. Hoffman  
NASA Johnson Space Center

### INTRODUCTION

- HISTORICALLY, THE BUSINESS OF ASTRONAUTS WAS TO GET THEIR SPACECRAFT TO ITS DESTINATION AND BACK AGAIN.
- SINCE SKYLAB, ASTRONAUTS HAVE HAD TIME IN ORBIT TO CARRY OUT EXTENSIVE PAYLOAD-ORIENTED OPERATIONS.
- SPACE STATION WILL CONTINUE THIS TRADITION.
- SPACE SHUTTLE FLIGHTS CARRY SUFFICIENT NUMBER OF CREW MEMBERS TO ALLOW SOME ASTRONAUTS TO BE DEVOTED TO PAYLOAD ACTIVITIES
  - EVA
  - RMS
  - DEPLOYMENTS
  - SCIENTIFIC INVESTIGATIONS

### MISSION APPLICATIONS

#### HIGH GROUND

- VIEW DOWN
  - METEOROLOGY
  - EARTH RESOURCES
  - OCEANOGRAPHY
  - ETC.
  - SYNERGISM BETWEEN SATELLITES AND CREW PHOTOGRAPHY
  - SPACE STATION LIMITED BY 28° ORBIT
- VIEW UP - IR, UV, X, GAMMA RAY ASTRONOMY
  - BEST SUITED FOR UNMANNED VEHICLES
  - FOR FUTURE PAYLOAD OPERATIONS, NEED HONEST TRADE STUDY BETWEEN COST OF MAINTAINABILITY AND COST OF FAILURES
- VIEW AROUND - PLASMA, AURORAL AND IONOSPHERIC STUDIES
  - COMBINE GEO, LEO AND GROUND STUDIES
  - TETHERS, UP AND DOWN, OFFER NEW METHODS OF STUDY

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.3 Payload Operations**

***Payload Operations from the Perspective of Manned Space Flight***

**Dr. Jeffrey A. Hoffman**  
NASA Johnson Space Center

**TECHNOLOGY NEEDS**

**HIGH GROUND**

- 1) ABILITY TO DEAL WITH EVER-INCREASING AMOUNTS OF DATA
- 2) TEST TETHER TECHNOLOGY
- 3) DEVELOP SATELLITE REPAIR, REFURBISHMENT AND REFUELING

**MISSION APPLICATIONS**

**MICROGRAVITY**

- HUMAN RESPONSE TO SPACE
  - THE ENVIRONMENT CREATES ITS OWN FIELD OF STUDY
- FUNDAMENTAL RESEARCH
  - FLUID PHYSICS
  - MATERIAL PROPERTIES
  - CRYSTAL GROWTH
  - BOTANY/ZOOLOGY
- APPLICATIONS
  - FIRE RESEARCH
  - EVENTUAL PRODUCTION PROCESSES

OVERWHELMING TECHNOLOGICAL NEED: **ABILITY TO USE SPACE AS A UNIQUE LABORATORY**

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.3 Payload Operations

#### *Payload Operations from the Perspective of Manned Space Flight*

Dr. Jeffrey A. Hoffman  
NASA Johnson Space Center

### TECHNOLOGY NEEDS

#### USE OF SPACE AS A LABORATORY

- MUST BALANCE UNIQUENESS OF ENVIRONMENT AGAINST OUR ACCUMULATED KNOWLEDGE OF HOW TO OPERATE IN A LAB.
- INTERACTIVE CREW OPERATIONS VS. AUTOMATION
  - USE OF HUMANS IS MOST VALUABLE DURING EARLY STAGES OF INVESTIGATIONS.
  - INCREASED UNDERSTANDING OF  $\mu$ -g PHENOMENA ALLOWS INCREASED USE OF AUTOMATION TO CREATE GREATER EFFICIENCY.
- EFFICIENT USE OF CREW TIME IS UNIQUE TO SPACE ENVIRONMENT
  - SPACE STATION MAY HAVE LESS CREW TIME THAN SHUTTLE
  - OBSERVE EXPERIMENTS IN PROGRESS
  - CHANGE PROTOCOL WHERE NECESSARY
  - REPAIR OR ALTER HARDWARE
- CLOSE UNION OF SCIENTIFIC ACTIVITIES ON GROUND AND ORBIT IS ESSENTIAL

#### TELESCIENCE

- HIGH DENSITY DATA AND COMMAND LINKS FOR GROUND OPERATIONS
  - VARIABLE FORMAT TV: RESOLUTION VS. SPEED VS. COLOR.
- EXPERIMENT DESIGN TO ALLOW EFFICIENT USE OF ONBOARD CREW
  - VISIBILITY
  - ACCESSIBILITY
- MAXIMIZE ABILITY TO REPEAT EXPERIMENTS AND ALTER VARIABLES.
- EXPERT SYSTEMS TO ASSIST CREW AND GROUND.
- FOR MATERIALS SCIENCE, SAMPLE RETURN CAPABILITY (SPACEMAIL).

### SUMMARY

- BALANCE BETWEEN SCIENTIFIC RESEARCH AND SPACEFLIGHT OPERATIONS
- EARLY INVOLVEMENT OF CREW CAN ENHANCE EXPERIMENTS

Theme 7 of 8

**IN-SPACE SYSTEMS**  
**7.3 Payload Operations**  
***Orbit Assembly Node***

Theme 7 of 8

Tom Styczynski / Lee R. Lunsford  
Lockheed Missiles & Space Company, Inc.

**INTRODUCTION / BACKGROUND**

**OBJECTIVE: ASSEMBLY, VERIFICATION, SERVICING, REPAIR & CORRECTION, AND REFURBISHMENT.**

**MISSIONS:**

- \* PLANETARY EXPLORATION MISSIONS - UNMANNED: PRECURSOR MISSION TO PLANETS AND MOONS WITHIN THE SOLAR SYSTEM.
- \* PLANETARY EXPLORATION MISSIONS - MANNED: LARGE TRANSIT VEHICLES, REFUELING & REFURBISHMENT STATIONS, etc.
- \* MISSION TO PLANET EARTH - ASSEMBLY AND TRANSFER OF VEHICLES TO SYN-EQ.
- \* LARGE SOLAR ELECTRIC ENERGY SYSTEMS.
- \* SPACE BASED MANUFACTURING & SERVICE FACILITIES.

**TECHNOLOGY NEEDS**  
**ORBIT ASSEMBLY AREA CONCEPT**  
**CRITICAL FUNCTIONS**

- \* PRECISION SCHEDULING.
- \* SELF-CONTAINED, AUTONOMOUS CHECK-OUT AND HEALTH STATUS.
- \* AUTONOMOUS STABILIZATION FOR ASSEMBLY OF ADDITIONAL COMPONENTS, ETC. - docking, berthing, positioning, orientation.
- \* PRECISION PLACEMENT: MICRO NAVIGATION, PRECISION ALIGNMENT AND ORIENTATION
- \* VISION CONTROL - focus, alignment, field of view, and shielding from the sun.
- \* AUTONOMOUS ASSEMBLY (ROBOT ASSEMBLY), TELE-ROBOTIC ASSEMBLY, & EVA ASSEMBLY.
- \* FUELING OR TOPPING OFF - PROPELLANT DEPOT OR TANKER
- \* PROTECTION OR HARDENING OF ASSEMBLY FROM SPACE DEBRIS AND SOLAR ILLUMINATION.
- \* VERIFICATION OF PROPER ASSEMBLY - PNEUMATIC, STRUCTURAL, etc.

Theme 7 of 8

**IN-SPACE SYSTEMS**  
**7.3 Payload Operations**  
***Orbit Assembly Node***

Theme 7 of 8

Tom Styczynski / Lee R. Lunsford  
Lockheed Missiles & Space Company, Inc.

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**AUTONOMOUS CHECK-OUT:**

SELF CONTAINED, AUTONOMOUS CHECK-OUT AND HEALTH STATUS WITH CAPABILITY FOR AUTONOMOUS INTEGRATION INTO THE NEXT HIGHER UNIT. CONCEPT SHOULD INCLUDE ACTIVATION OF THE AUTONOMOUS SYSTEM AT SHIPMENT FROM THE FACTORY. NETWORKING AND SOFTWARE SHOULD PROVIDE CONTINUOUS READOUT (i.e., 10 TIMES PER SECOND).

**CRITICAL TECHNOLOGIES: - SENSORS, NETWORKING, & SOFTWARE:**

- \* SENSORS REQUIREMENTS INCLUDE: ELECTRICAL, ELECTRONIC, STRUCTURES, MECHANICAL (i.e., LOCKED OR UNLOCKED), POSITION, LEAKAGE, PRESSURE, EXPENDABLES AVAILABLE (i.e., ZERO "G" MEASURE OF REMAINING PROPELLANTS), TEMPERATURE, VIBRATION & SOUND/PRESSURE LEVELS, STRESS & STRAIN, AND SEQUENCE OF EVENTS.
- \* NETWORKING: POWER, DATA AND COMMAND NETWORKING WILL BE REQUIRED WITH CAPABILITY OF AUTONOMOUS INTEGRATION INTO THE NEXT HIGHER UNIT UPON ASSEMBLY - BOTH HARDWARE AND SOFTWARE PROBLEM.
- \* SOFTWARE: COMMAND AND CONTROL, SENSOR DATA PROCESS & EVALUATION, REPORTING CRITERIA (i.e., RECORD EVENT, REPORT EVENT, OR SOUND ALARM).

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**AUTONOMOUS PLACEMENT:**

AUTONOMOUS ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, GRASPING OR MATING, PRECISION PLACEMENT OR INSERTION AND ASSEMBLY.

**CRITICAL TECHNOLOGIES:**

- \* VISION: ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, EVALUATION AND CONTROL
- \* AUTONOMOUS STABILIZATION FOR ASSEMBLY: STABILIZATION DURING DOCKING, BERTHING, POSITIONING, AND ORIENTATION FOR ASSEMBLY.
- \* MICRO-NAVIGATION: TO SUPPORT PRECISION PLACEMENT, INSERTION, OR LOCATION OF DEFECTIVE PART.
- \* PRECISION ATTITUDE DETERMINATION AND CONTROL: TO SUPPORT LOCATION AND IDENTIFICATION, PLACEMENT AND ORIENTATION.
- \* VERIFICATION: VERIFICATION OF ASSEMBLY TO INCLUDE MECHANICAL, ELECTRICAL, ELECTRONIC, PNEUMATIC, HYDRAULIC, STRUCTURAL, POSITION LOCATION & ORIENTATION.
- \* END EFFECTORS: FOR GRASPING, HOLDING, MANIPULATING, POSITIONING, ORIENTING, AND INSERTING.

Theme 7 of 8

**IN-SPACE SYSTEMS**  
**7.3 Payload Operations**  
***Orbit Assembly Node***

Theme 7 of 8

Tom Styczynski / Lee R. Lunsford  
Lockheed Missiles & Space Company, Inc.

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**AUTONOMOUS REPLACEMENT OF PARTS :**

AUTONOMOUS ACQUISITION, RECOGNITION/IDENTIFICATION, LOCATION, GRASPING OR ATTACHMENT, OPENING OF COVER OR PANELING, LOCATION, GRASPING & REMOVAL OF DEFECTIVE PART, FOLLOWED BY INSERTION OF REPLACEMENT PART, CLOSING OF COVER OR PANEL, AND VERIFICATION OF PERFORMANCE. REPEAT FOR ELECTRICAL/ELECTRONIC PARTS, PNEUMATIC PARTS, HYDRAULIC (i.e., PROPELLANT) PARTS, AND MECHANICAL COMPONENTS.

**CRITICAL TECHNOLOGIES :**

- \* DEVELOPMENT OF COMPATIBLE ASSEMBLY COMPONENTS AND ROBOT CONCEPTS.
- \* HIGHER LEVEL OF AUTOMATION, FORCE FEEDBACK END EFFECTORS, ETC.
- \* SELF-LOCATION, ORIENTATION, MICRO NAVIGATION.
- \* VISION SYSTEM CAPABLE OF SENSING PLACEMENT OR INSERTION ACTIVITY IN A CLOSED LOOP.
- \* POSITIONING AND ORIENTATION.
- \* VERIFICATION OF PERFORMANCE - i.e., UNLOCKING, & LOCKING.

**SUMMARY / RECOMMENDATIONS**

\* **SYSTEM TRADES:**

- ASSEMBLY FACILITY VS. ASSEMBLY AREA WITH ENHANCED SPACE STATION
- ORBITAL PROPELLANT DEPOT VS. TRANSPORT WITH PROPELLANT & TOP OFF FROM TANKER

\* **CRITICAL TECHNOLOGIES:**

- NETWORKING, SOFTWARE, & SENSORS FOR AUTONOMOUS CHECK-OUT AND HEALTH STATUS.
- VISION CONTROL - CLOSED LOOP ACQ., RECOGNITION, LOCATION, & EVALUATION.
- PRECISION PLACEMENT - MICRO NAVIGATION, PRECISION ATTITUDE CONTROL, AUTONOMOUS STABILIZATION TO SUPPORT PLACEMENT.
- VERIFICATION OF ASSEMBLY FUNCTIONS.

\* **IN-SPACE EXPERIMENTATION**

- SELF CONTAINED CHECK-OUT AND HEALTH STATUS WITH CAPABILITY OF INTEGRATION INTO THE NEXT HIGHER UNIT.
- AUTONOMOUS PRECISION PLACEMENT AND ASSEMBLY
- AUTONOMOUS REPLACEMENT OF COMPONENTS & SUB-ASSEMBLIES

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.3 Payload Operations**

***In-Space Systems: Space Construction and Payload Operations***

**George W. Morgenthauer**

University of Colorado, Aerospace Engineering Sciences Dept., Center for Space Construction

**INTRODUCTION/BACKGROUND**

- Humanity is entering 2nd ERA of the Space Age:
  - 1st Era:
    - Space flight realization, 1957-1987
  - 2nd Era:
    - Space exploration and base activation, 1987-2027
  - 3rd Era:
    - Space colonization and utilization, 2027--
- Parallel to man's Arctic and Antarctic activities:
  - Visit the Poles; Establish scientific bases; Alaskan pipeline;  
Canadian Arctic Center
- Long-term Space Mission Planning--many destinations, many decades:
  - National Commission on Space Report, 1986
  - Dr. Sally Ride's Report, 1987
  - NASA's Pathfinder Program
  - President Reagan's National Space Policy, 1988
- Consensus: Explore and utilize the Solar System; develop space commercially.
- Space Program Philosophy:
  - Building Block Approach;
  - International participation;
  - Mission model optimization, not single mission optimization only.

**MISSION APPLICATIONS**

- Mission Model Identified:
  - Large unmanned laboratories, antenna arrays, telescopes, etc.
  - Mission to Planet Earth (Remote Sensing)
  - Space Stations and Platforms
  - On-orbit Assembly of Manned Interplanetary Spacecraft
  - Lunar Base
  - Mars Base
- Demands for increased scientific data operations
- Space construction instead of delivering entire space structure at one launch
- Astronaut work limitations
- Astronaut environmental protection required

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.3 Payload Operations**

***In-Space Systems: Space Construction and Payload Operations***

**George W. Morgenthauer**

University of Colorado, Aerospace Engineering Sciences Dept., Center for Space Construction

**TECHNOLOGY NEEDS**

- **Orbital logistics needs** - Determine optimum mix of launch vehicles:  
large vs small, unmanned vs man-rated
- **Telecommunication needs:**
  - Construction phase telecommunication
  - improve telecommunication for operations and experiment telescience (OASIS)
- **In-space Construction and Operation needs:**
  - Type and intelligence (autonomy) of robots?
  - Bionic devices for astronauts?
  - Optimum astronaut/robot mix?
- **Space Environment protection needs:**
  - meteoroid/debris
  - radiation
  - thermal
  - pressure

**SPACE TELECOMMUNICATIONS EXPERIMENTS FOR CONSTRUCTION/OPERATIONS**

- **The time-delay problem**
- **The security blanket problem**
- **The Steady-State Telecommunications System design problem**
- **The emergency support problem: equipment failure/medical crisis--  
AI implications**
- **The Tower of Babel Problem**

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.3 Payload Operations**

***In-Space Systems: Space Construction and Payload Operations***

**George W. Morgenthauer**

University of Colorado, Aerospace Engineering Sciences Dept., Center for Space Construction

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

- **Telecommunications System**
  - **Develop and test Telecommunications System for Space Construction Phase**
  - **Experiment with time-delay command-control**
- **OASIS system development and test (for operating space experiments)**
- **ET Space Experiments:**
  - **Lower-Thermosphere Density Experiment**
  - **Space Meteoroid/Debris monitoring experiment**
  - **Fluid vibration generation experiment**
  - **Space thruster experiment**
  - **Explosive fastening experiment**
- **Macro-Planning Model Development**

**SUMMARY AND RECOMMENDATIONS**

- **Plans for Space Construction Needs as well as Space Operations Needs.**
- **Develop standardized Construction-Phase and Steady-State Telecommunications for transmission of voice, video, data, computer, teleoperators commands in presence of time delays.**
- **Develop and Test a 1990's, user-friendly, teleoperator/telescience work-station, e.g., OASIS.**
- **Utilize the ET as well as ELV's and Shuttle Orbiter to provide knowledge of Space Environment.**
- **Develop a Macro-Planning Model for optimizing planning of a multi-year, multi-destination Space Program Mission Model.**

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.3 Payload Operations

#### *In-Space Systems Critical Technology Requirements*

Jon B. Haussler  
NASA Marshall Space Flight Center

## IN-SPACE SYSTEMS THEME

### THEME ELEMENTS

- MATERIALS PROCESSING
- MAINTENANCE, REPAIR, AND FIRE SAFETY
- PAYLOAD OPERATIONS

## EXPLANATION OF MATERIALS PROCESSING NEEDS

- UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT. SPACE ENVIRONMENT INCLUDES MICRO G AND / OR ULTRA HIGH VACUUM. WE ARE ESPECIALLY CONCERNED WITH UNDERSTANDING A RANGE OF DYNAMIC PROCESSES IN MICRO-G, INCLUDING (BUT NOT LIMITED TO):
  - THERMOCAPILLARY FLOW
  - GAS/LIQUID/SOLID PHASE SEPARATION AND INTERFACE BEHAVIOR
  - DIFFUSION AND PERMEABILITY
  - WETTING
- DEMONSTRATION OF INNOVATIVE IN SPACE SAMPLE ANALYSIS TECHNIQUES. THESE SAMPLE ANALYSIS TECHNIQUES SHOULD FOCUS ON REDUCING THE SIZE, MASS AND/OR HAZARDS OF CONVENTIONAL TECHNIQUES SUCH AS SCANNING ELECTRON MICROSCOPE, XRAY FLUORESCENCE, WET CHEMICAL PROCESSING AND THE LIKE.
- CHARACTERIZATION AND MANAGEMENT OF THE MICRO G ENVIRONMENT. IN PARTICULAR THERE IS A CRITICAL NEED FOR IN SITU MEASUREMENT OF G LEVELS FROM  $10^5$  G TO  $10^8$  G AT FREQUENCIES  $\cdot 1$  Hz ; PASSIVE AND ACTIVE VIBRATION ISOLATION AT LOW FREQUENCIES, AND THE REALISTIC ASSESSMENT OF G LEVEL REQUIREMENTS FOR BIOLOGICAL AND PHYSICAL EXPERIMENTS.
- DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS. WE NEED TO DEVELOP AND DEMONSTRATE ENABLING TECHNOLOGIES WHICH ALLOW FOR REAL-TIME MONITORING, NON CONTACT TEMPERATURE MEASUREMENT, MINATURIZATION OF SENSORS AND IMPROVED IMAGE ANALYSIS.
- DEMONSTRATION OF AUTOMATION AND ROBOTIC APPLICATIONS TO MATERIAL PROCESSING SYSTEMS. THERE IS A NEED FOR DEVELOPMENT OF EXPERT SYSTEMS AND REACTIONLESS ROBOTS FOR MATERIALS PROCESSING.

Theme 7 of 8

## IN-SPACE SYSTEMS

Theme 7 of 8

### 7.3 Payload Operations

#### *In-Space Systems Critical Technology Requirements*

Jon B. Haussler  
NASA Marshall Space Flight Center

## MATERIALS PROCESSING

AN ALL ENCOMPASSING DEFINITION OF MATERIALS  
IS USED IN THIS ELEMENT.

#### PRIORITY:

1. UNDERSTANDING OF MATERIALS BEHAVIOR IN SPACE ENVIRONMENT
2. DEMONSTRATION OF INNOVATIVE IN-SPACE SAMPLE ANALYSIS TECHNIQUES
2. CHARACTERIZATION AND MANAGEMENT OF THE MICRO-G ENVIRONMENT
3. DEMONSTRATION OF IMPROVED SENSING AND IMAGING TECHNIQUES IN EXPERIMENTAL SYSTEMS
4. DEMONSTRATION OF AUTOMATION AND ROBOTICS APPLICATIONS TO MATERIAL PROCESSING SYSTEMS

#### CONSENSUS CONCERN:

WASTE PRODUCTS FROM MATERIAL PROCESSING

## MAINTENANCE, REPAIR AND FIRE SAFETY

#### PRIORITY:

1. DEMONSTRATION AND VALIDATION OF CAPABILITY TO REPAIR UNEXPECTED EVENTS
1. INVESTIGATION OF LOW-G IGNITION, FLAMMABILITY/FLAME SPREAD AND FLAME CHARACTERISTICS
2. DEMONSTRATION AND VALIDATION OF FLUID REPLENISHMENT TECHNIQUES
2. UNDERSTAND BEHAVIOR OF FLAME EXTINGUISHANTS IN SPACE ENVIRONMENT
3. DEMONSTRATE ROBOTIC MAINTENANCE AND REPAIR CAPABILITY

CONSENSUS INTERESTING IDEA:  
SIMULATED ACCIDENT SCENARIOS

Theme 7 of 8

**IN-SPACE SYSTEMS**

Theme 7 of 8

**7.3 Payload Operations**

***In-Space Systems Critical Technology Requirements***

**Jon B. Haussler**  
NASA Marshall Space Flight Center

**PAYLOAD OPERATIONS**

**PRIORITY:**

1. **DEMONSTRATION AND VALIDATION OF TELESCIENCE TECHNIQUES**
2. **DEMONSTRATION OF AUTONOMOUS CHECKOUT,  
PLACEMENT AND SPACE CONSTRUCTION**

**CONSENSUS CONCERNS:**

- **RAPID SAMPLE RETURN**
- **ORBITAL DEBRIS**

Theme 8 of 8

## **HUMANS IN SPACE**

Theme 8 of 8

Background and Objectives

*Overview: EVA, Performance, Life Support Systems*

**Remus Bretol**  
NASA Ames Research Center

## **HUMANS IN SPACE**

### **THEME OVERVIEW**

### **THEME SESSION OBJECTIVES**

### **DESCRIPTION OF THEME & THEME ELEMENTS**

### **BACKGROUND OF THEME TECHNOLOGY DEVELOPMENT**

### **PROGRESS SINCE 1985 WORKSHOP**

### **THEME SESSION AGENDA**

### **PRIORITIZATION CRITERIA**

### **SUMMARY**

## **THEME SESSION OBJECTIVES**

### **PURPOSE**

- o Identify & Prioritize In-Space Technologies for Humans In Space Which:
  - Are Critical for Our Future Space Programs, & Need Development & In-Space Validation.
- o Obtain Aerospace Community Comments & Suggestions on OAST IN-STEP Plans

### **PRODUCT**

Aerospace Community Recommended Priority Listing of Critical Space Technology Needs & Associated Space Flight Experiments

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

Background and Objectives

***Overview: EVA, Performance, Life Support Systems***

**Remus Bretol**  
NASA Ames Research Center

**DESCRIPTION OF THEME & THEME ELEMENTS**

**EVA/SUIT**

**HUMAN PERFORMANCE**

**CLOSED-LOOP LIFE SUPPORT SYSTEMS**

**EVA/SUIT**

**SUITS & EQUIPMENT**

**Pressure Suit Technology**  
**Glove Technology**  
**End-Effector Technology**  
**Mobility Aids**  
**Tools**  
**Displays & Controls**  
**Interfaces**

**PORTABLE LIFE SUPPORT SYSTEMS**

**Thermal Control**  
**Atmosphere Control**  
**Automated Control Technology**  
**Display Technology**  
**Regeneration Equipment**

**LOGISTICS & SUPPORT**

**Diagnostics**  
**Displays & Controls**  
**Maintenance & Repair**  
**Inventory Management & Supply**  
**Information Management**

Theme 8 of 8

## **HUMANS IN SPACE**

Theme 8 of 8

Background and Objectives

*Overview: EVA, Performance, Life Support Systems*

Remus Bretol  
NASA Ames Research Center

### **HUMAN PERFORMANCE**

#### **CREW & ENVIRONMENTAL FACTORS**

Organization and Management  
Crew Coordination  
Environmental & Mission Task  
Training and Intervention

#### **HUMAN-MACHINE INTERACTION**

Crew Support and Enhancement  
Human-Automation-Robotics (HAR)

#### **ARTIFICIAL GRAVITY & ADV. COUNTERMEASURES**

##### **ARTIFICIAL GRAVITY**

Rotation Rate  
Intermittent G vs Continuous Exposure  
Partial G and G Threshold  
Structural Facility Impact

##### **ADVANCED COUNTERMEASURES**

Electromyostimulation  
Pharmacological Tests  
Autogenic Feedback  
Pre-Adaptation Training

Theme 8 of 8

## **HUMANS IN SPACE**

Theme 8 of 8

Background and Objectives

***Overview: EVA, Performance, Life Support Systems***

Remus Bretol  
NASA Ames Research Center

### **CLOSED-LOOP LIFE SUPPORT SYSTEMS**

#### **PHYSICAL/CHEMICAL CLOSED-LOOP LIFE SUPPORT**

Water Reclamation  
Waste Management  
Thermal Control  
Monitoring & Control Instrumentation  
Air Revitalization

### **THEME BACKGROUND**

#### **TECHNOLOGY DEVELOPMENT**

**HUMANS IN SPACE** was not a theme in the 1985 Workshop.  
It is a new addition to the IN-STEP / Outreach Program.

**RELATED STUDY EFFORTS** resulting from the 1985  
Workshop were:

Spatial Perception Auditory Referencing  
Microbiology Monitor  
Closed-Loop Nutrient Solution Delivery System  
Water Electrolysis Operation

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

Background and Objectives

*Overview: EVA, Performance, Life Support Systems*

Remus Bretol  
NASA Ames Research Center

**AGENDA**

Wednesday December 7th

**CRITICAL SPACE TECHNOLOGY & IN-SPACE  
EXPERIMENTS NEEDS**

**(PRESENTATIONS and DISCUSSIONS)**

**EVA/SUIT PRESENTATIONS**

Bruce W. Webbon / Bernadette Squire (NASA-ARC)  
H. Thomas Fisher (Lockheed Corporation)  
David L. Akin (MIT, Aeronautics and Astronautics Dept)

**EVA/SUIT OPEN DISCUSSION**

Questions & Answers With Speakers  
Identification of Additional Technologies/Experiments

**HUMAN PERFORMANCE PRESENTATIONS**

Barbara Kanki (NASA-Ames Research Center)  
Lawrence G. Lemke (NASA-HQ / Office of Exploration)  
Wm. Russell Ferrell (University of Arizona, Tucson)

**HUMAN PERFORMANCE OPEN DISCUSSION**

Questions & Answers With Speakers  
Identification of Additional Technologies/Experiments

Theme 8 of 8

**HUMANS IN SPACE**  
Background and Objectives  
*Overview: EVA, Performance, Life Support Systems*

Theme 8 of 8

**Remus Bretol**  
NASA Ames Research Center

**AGENDA**

WEDNESDAY DECEMBER 7th

**CLOSED-LOOP LIFE SUPPORT SYSTEMS  
PRESENTATIONS**

**Robert D. MacElroy (NASA - Ames Research Center)**  
**Richard L. Olson/Thomas J. Slavin (Boeing Aerospace)**  
**Marvin Luttges (University of Colorado, Boulder)**

**CLOSED-LOOP LIFE SUPPORT SYSTEMS OPEN**

**Questions & Answers With Speakers**  
**Identification of Additional Technologies/Experiments**

THURSDAY, DECEMBER 8th

**PRIORITIZE CRITICAL TECHNOLOGIES (AUDIENCE)**  
**COMBINE & PRIORITIZE THEME TECHNOLOGIES**

FRIDAY DECEMBER 9th

**THEME LEADER PRESENTATIONS TO GENERAL SESSION**  
**WORKSHOP WRAP-UP**

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

Background and Objectives

*Overview: EVA, Performance, Life Support Systems*

Remus Bretol  
NASA Ames Research Center

**PRIORITIZATION CRITERIA\***

1. **CRITICAL ENABLING TECHNOLOGIES**  
Technologies critical for future space missions
2. **COST REDUCTION TECHNOLOGIES**  
Technologies which can decrease costs or complexity  
(e.g., development, opns, life-cycle)
3. **BROAD APPLICATION TECHNOLOGIES**  
Technologies which can improve or enhance a variety of  
space missions
4. **REQUIRE IN-SPACE VALIDATION**  
Technologies which require the space environment or  
micro-gravity for validation or experimentation

\* CRITERIA ARE LISTED IN ORDER OF IMPORTANCE (1 IS HIGHEST)

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.1 EVA / Suit**

***EVA Technology***

**Dr. Bruce W. Webbon / Bernadette Squire**  
NASA Ames Research Center, Crew Research and Space Human Factors Branch

**INTRODUCTION/BACKGROUND**

**CURRENT EVA SYSTEM LIMITATIONS**

- Low working pressures (productivity impacts)
- Limited mobility
- Marginal crew comfort
- Marginal glove acceptability
- Large consumable mass
- Maintenance and servicing
- Protection from environmental hazards
- Bends risk
- High life-cycle costs
- Growth potential
- Working period limitations
- Sizing repeatability

**TECHNOLOGY NEEDS**

**SYSTEMS STUDIES**

• **MISSION REQUIREMENTS DEFINITION**

Environmental, Task, Design Reference Mission

• **HUMAN REQUIREMENTS DEFINITION**

Human Factors, Physiological, Medical

• **EVA WORK SYSTEMS INTEGRATION**

Modeling, Trade Studies, Interface Definition,  
Logistics, Support, Test Requirements

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.1 EVA / Suit**

***EVA Technology***

**Dr. Bruce W. Webbon / Bernadette Squire**

NASA Ames Research Center, Crew Research and Space Human Factors Branch

**TECHNOLOGY NEEDS**

**PORTABLE LIFE SUPPORT SYSTEM (PLSS)**

- **THERMAL CONTROL SYSTEMS**  
Heat Storage, Acquisition, Transport, Rejection
- **ATMOSPHERE CONTROL**  
O2 Supply, CO2 Control, Trace Contaminant  
Control, Humidity Control
- **MONITORING & CONTROL**  
Automated Control, Display Technology
- **SYSTEM INTEGRATION**  
Support Equipment and Interfaces

**EVA SUITS & EQUIPMENT**

- **PRESSURE SUIT TECHNOLOGY**  
Materials, Structures, Components, Mobility  
Elements
- **GLOVES & END-EFFECTORS**
- **EVA ANCILLARY EQUIPMENT**  
Mobility Aids, Tools, Displays & Controls,  
Work System Interfaces
- **SYSTEM INTEGRATION & TEST**  
Logistics & Support

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.1 EVA / Suit**

***EVA Technology***

**Dr. Bruce W. Webbon / Bernadette Squire**  
NASA Ames Research Center, Crew Research and Space Human Factors Branch

**SUMMARY / RECOMMENDATIONS**

**Determine (empirically):**

**EVA Physiological/Metabolic Parameters  
Thermal Environment Parameters**

**Characterize:**

**EVA Biomechanics in Reduced-g  
g-Sensitivity of Phase Change Processes**

**Demonstrate:**

**Radiation Protection (Mars Transit)  
Radiator/Refrigeration System  
Electrochemical Regeneration of CO<sub>2</sub>  
Voice Technology for Control Applications  
Countermeasures for Bearing Blocking, Cold Welding  
Advanced Pressure Suit Technology in Zero-g  
High Pressure Gloves  
End-Effector Use in EVA Tasks**

Theme 8 of 8

## HUMANS IN SPACE

Theme 8 of 8

### 8.1 EVA / Suit

#### *Extra-Vehicular Activity / Suit*

H.T. Fisher

Lockheed Missiles & Space Co., Inc., Astronautics Division, Space Station Program

1. THERE IS NO DOUBT EVA IS A CRITICAL TECHNOLOGY TO NASA CURRENT SPACE ACTIVITIES AND FUTURE MISSION PLANS
2. EVA HAS UNIVERSIAL APPLICABILITY & MULTI-MISSION UTILITY
3. PRESENT EVA TECHNOLOGY IS EVOLVING TO ENHANCE:
  - CREW PRODUCTIVITY
  - RISK REDUCTION
  - MISSION FLEXIBILITY
  - ALTERNATIVE PATHS
4. NASA & DoD MAY SHARE COMMON NEEDS - E.G., CANDIDATE DoD MILITARY MANNED SPACE OPERATIONS
5. CERTAIN EVA TECHNOLOGIES ARE WELL UNDERWAY WHILE OTHERS ARE LAGGING OR ARE NOT BEING WORKED
6. MOST ADVANCED EVA PROGRAM EFFORT IS WITHIN THE NASA WITH LITTLE AEROSPACE/COMMERCIAL INDEPENDENT VENTURES
7. LIMITED, BUT IMPORTANT ADVANCED EVA PLANETARY STUDY WORK IS JUST BEING INITIATED & MORE IS PLANNED (?) VIA PATHFINDER - NASA-JSC/AMES
8. IT APPEARS PRUDENT TO RE-ASSESS WHERE EVA TECHNOLOGY IS HEADED

#### **EVA ENCLOSURE & LIFE SUPPORT**

- EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION
- RAPID CREW 'IN-SITU' SUIT SERVICING
- PROTECTION AGAINST RADIATION HAZARDS
- RAPID EVA ACCESS - LSS COMPATIBILITY WITH S/C
- ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF

#### **EVA SUPPORT EQUIPMENT**

- SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT
- SMALL LT-WT PORTABLE AIRLOCK
- SMALL LT-WT PORTABLE SURFACE TRANSPORTER (EV CREW/EQUIP)
- SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER
- MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT
- CREW & EQUIP TRANSPORTER & POSITIONING AID
- CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT
- ADVANCED MANEUVERING UNIT
- EMERGENCY SUIT 'LIFE JACKET'
- EMERGENCY EVA SURVIVAL GEAR
- SUIT CONTAMINATION DETECTION & CLEANING UNIT
- DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS
- ADVANCED POWER TOOLS FOR EVA
- PORTABLE EVA EXPER/SURVEY/SAMPLE KIT
- PORTABLE MULTI-PURPOSE AVIONIC UNIT

Theme 8 of 8

# HUMANS IN SPACE

Theme 8 of 8

## 8.1 EVA / Suit

### Extra-Vehicular Activity / Suit

H.T. Fisher

Lockheed Missiles & Space Co., Inc., Astronautics Division, Space Station Program

DEVELOPMENT FACTORS DEVELOPMENT ELEMENTS	MISSION CRITICALITY		NEED DATE	STATUS
	FUNDING LEVEL			
<b>EVA ENCLOSURE &amp; LIFE SUPPORT</b>				
• EXTENDED LSS DURATION	L-M	H	96	R&D(P)
• RAPID CREW 'IN-SITU' SUIT SERVICING	L-M	H	96	R&D(P)
• PROTECTION AGAINST RADIATION HAZARDS	L	M-H	2000	R&D(P)
• RAPID EVA ACCESS - LSS COMPATIBILITY WITH S/C	L-M	H	96	R&D
• ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF	L	M-H	95	R&D
<b>EVA SUPPORT EQUIPMENT</b>				
• SMALL LT-WT PORT. HYPERBARIC TREATMENT UNIT	L	H	2000	R&D
• SMALL LT-WT PORTABLE AIRLOCK	L-O	H	2000	STUDY
• SMALL LT-WT PORT. SURFACE TRANSPORTER	O	M-H	2005	STUDY
• SMALL LT-WT PORT. RAD/THERMAL/WIND SHELTER	O	H	2005	STUDY
• MULTI-PURPOSE EVA WORK STA. & MOTOR. FT RESTR.	L	H	95	R&D(P)
• CREW & EQUIP TRANSPORTER & POSITIONING AID	L	H	95	R&D(P)
• CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT	L	H	95	R&D(P)
• ADVANCED MANEUVERING UNIT	O	H	98	STUDY
• EMERGENCY SUIT 'LIFE JACKET'	O	M-H	2005	STUDY
• EMERGENCY EVA SURVIVAL GEAR	O	M-H	2000	STUDY
• SUIT CONTAMINATION DETECTION & CLEANING UNIT	L	H	95	R&D(P)
• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOW. UNITS	L-O	L-M	98	STUDY
• ADVANCED POWER TOOLS FOR EVA	L	M	98	R&D(P)
• PORTABLE EVA EXPR/SURVEY/SAMPLE KIT	O	L-M	2005	STUDY
• PORTABLE MULTI-PURPOSE EVA AVIONIC UNIT	O	M	2005	STUDY
KEY: L = LOW M = MODERATE H = HIGH PARTIAL = P				

DEVELOPMENT FACTORS DEVELOPMENT ELEMENTS	TECHNOLOGY STATUS/VOIDS
<b>EVA ENCLOSURE &amp; LIFE SUPPORT</b>	
• RAPID EVA ACCESS-LSS COMPAT. WITH 14.7 PSIA CREW COMPT.	TECH IN WORK*
• RAPID CREW 'IN-SITU' SUIT SERVICING	TECH IN WORK*
• EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION	TECH IN WORK*
• PROTECTION AGAINST RADIATION HAZARDS	TECH IN WORK*
• ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF	TECH IN WORK
<b>EVA SUPPORT EQUIPMENT</b>	
• CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT	SOME NEW TECH NEEDED
• SUIT CONTAMINATION DETECTION & CLEANING UNIT	TECH VOID
• ADVANCED MANEUVERING UNIT	TECH BUILD-ON/NO ONGO
• MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT	SOME NEW TECH NEEDED
• CREW & EQUIP TRANSPORTER & POSITIONING AID	BREADBOARD-WK REQD
• SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT	TECH IN WORK*
• SMALL LT-WT PORTABLE AIRLOCK	NO ONGO WK+TECH VOID
• EMERGENCY SUIT 'LIFE JACKET'	NO ONGO WK+TECH VOID
• EMERGENCY EVA SURVIVAL GEAR	NO ON GOING WORK
• ADVANCED POWER TOOLS FOR EVA	SOME NEW TECH-WK REQ
• DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS	NO SIG. ON GOING WORK
• SMALL LT-WT PORTABLE SURFACE TRANSPORTER-EVA CREW/EQUIP	MIN ON GOING WORK
• SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER	TECH VOID
• PORTABLE MULTI-PURPOSE AVIONIC UNIT	NO SIG ON GOING WORK
• PORTABLE EVA EXPR/SURVEY/SAMPLE KIT	NO ON GOING WORK

\* TECH. IN WORK BUT NOT CONSIDERED FIRM FOR IMMEDIATE ELEMENT RDT&E GO-AHEAD

Theme 8 of 8

HUMANS IN SPACE

Theme 8 of 8

8.1 EVA / Suit

*Extra-Vehicular Activity / Suit*

H.T. Fisher

Lockheed Missiles & Space Co., Inc., Astronautics Division, Space Station Program

**EVA ENCLOSURE & LIFE SUPPORT**

- DEMONSTRATE RAPID SUIT DON & EV EGRESS IN 14.7 PSIA ENVIRONMENT
- DEMONSTRATE & VALIDATE 'AUTOMATED' & SHORT-TURN-AROUND ON-ORBIT SUIT SERVICING
- DEMONSTRATE EXTENDED SUIT LIFE SUPPORT SYSTEM DURATION & UTILITY BENEFITS
- DEMONSTRATE ALTERNATIVES IN 0-G AGAINST RADIATION HAZARDS
- DEMONSTRATE BASIC &/OR ALTERNATIVES TO AUDIO/DISPLAYED INFORMATION TO THE CREW

**EVA SUPPORT EQUIPMENT**

- DEMONSTRATE & VALIDATE ZERO/LOW-G CREW/EQUIPMENT RECOVERY/RETRIEVAL UNIT
- DEMONSTRATE CONTAMINATION ACQUISITION, VALIDATE SPECIES IDENT., & EVAL. REMOVAL TECHNIQUES
- DEMONSTRATE & VALIDATE ZERO/LOW-G ADVANCED MANEUVERING UNIT
- DEMONSTRATE & EXAMINE RANGE OF MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT
- DEMONSTRATE, EVAL. UTILITY/RANGE, & ASSESS PWR/UNPOWERED CREW/EQUIP XPORTER/POSITION AID
- DEMONSTRATE & VALIDATE SMALL LT-WEIGHT PORTABLE HYPERBARIC TREATMENT UNIT
- DEMONSTRATE & VALIDATE SMALL LT-WEIGHT PORTABLE AIRLOCK
- EXAMINE & ASSESS ALTERNATIVES FOR A SUIT 'LIFE JACKET'
- DEMONSTRATE & ASSESS CAPABILITY & UTILITY OF EVA SURVIVAL GEAR
- DEMONSTRATE & ASSESS EVA POWER TOOLS, E.G., CUTTERS, DRILLS, WELDERS, BONDERS, ETC.
- DEMONSTRATE & ASSESS UTILITY & SAFETY OF DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS
- DEMONSTRATE & ASSESS UTILITY OF MULTI-TERRAIN SMALL LT-WT PORT. SURFACE TRANSPORTER
- DEMONSTRATE & ASSESS SET-UP/USE OF RAPID DEPLOY ZERO/LOW-G RAD/THERMAL/WIND SHELTER
- DEMONSTRATE UTILITY & VALIDATE PORTABLE MULTI-PURPOSE AVIONIC UNIT
- DEMONSTRATE UTILITY & FLEXIBILITY OF PORTABLE EVA EXPR/SURVEY/SAMPLE KIT

**PRIORITY**

**DEVELOPMENT ELEMENTS**

**EVA ENCLOSURE & LIFE SUPPORT**

- |   |   |
|---|---|
| • RAPID EVA ACCESS-LSS COMPAT. WITH 14.7 PSIA CREW COMPT. | 1 |
| • RAPID CREW 'IN-SITU' SUIT SERVICING                     | 2 |
| • EXTENDED PERSONAL LIFE SUPPORT SYSTEM DURATION          | 3 |
| • PROTECTION AGAINST RADIATION HAZARDS                    | 4 |
| • ENHANCED AUDIO/HEADS-UP DISPLAY & WRIST CUFF            | 5 |

**EVA SUPPORT EQUIPMENT**

- |   |    |
|---|----|
| • CREW & EQUIPMENT RECOVERY/RETRIEVAL UNIT                  | 1  |
| • SUIT CONTAMINATION DETECTION & CLEANING UNIT              | 2  |
| • ADVANCED MANEUVERING UNIT                                 | 3  |
| • MULTI-PURPOSE EVA WORK STA. & MOTORIZED FOOT RESTRAINT    | 4  |
| • CREW & EQUIP TRANSPORTER & POSITIONING AID                | 5  |
| • SMALL LT-WT PORTABLE HYPERBARIC TREATMENT UNIT            | 6  |
| • SMALL LT-WT PORTABLE AIRLOCK                              | 7  |
| • EMERGENCY SUIT 'LIFE JACKET'                              | 8  |
| • EMERGENCY EVA SURVIVAL GEAR                               | 9  |
| • ADVANCED POWER TOOLS FOR EVA                              | 10 |
| • DEBRIS/LOOSE EQUIP. HANDLING AIDS/STOWAGE UNITS           | 11 |
| • SMALL LT-WT PORTABLE SURFACE TRANSPORTER (EVA CREW/EQUIP) | 12 |
| • SMALL LT-WT PORTABLE RADIATION/THERMAL/WIND SHELTER       | 13 |
| • PORTABLE MULTI-PURPOSE AVIONIC UNIT                       | 14 |
| • PORTABLE EVA EXPR/SURVEY/SAMPLE KIT                       | 15 |

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.1 EVA / Suit**

***Extra-Vehicular Activity / Suit***

H.T. Fisher

Lockheed Missiles & Space Co., Inc., Astronautics Division, Space Station Program

**SUMMARY**

- 1. NASA & CANDIDATE DoD MANNED MISSIONS PRESENTED & TECHNOLOGY NEEDS RELATED TO EACH AND TO NASA 'MODEL' SCHEDULE**
- 2. TECHNOLOGY NEEDS IDENTIFIED AND DEVELOPMENT FACTORS INDICATED**
- 3. RATIONALE FOR EVA SYSTEM HDWR DEVELOPMENT PORTRAYED**

**CONCLUSIONS**

- 1. TOTAL/ALL-UP SUIT TECHNOLOGY NOT YET IMMEDIATELY READY FOR FULL RDT&E PUSH**
  - TECHNOLOGY IS BEING WORKED HARD AT NASA-JSC/AMES**
- 2. MANY EVA EQUIP. ELEMENTS IN BRASSBOARD DEVELOPMENT STATE**
- 3. CERTAIN EVA EQUIPMENT NOT BEING WORKED RELATIVE TO MISSIONS IMMEDIATELY BEYOND FREEDOM SPACE STATION ASSEMBLY**
- 4. MANY STATION EVA ELEMENTS LEND THEMSELVES TO ORBITER PRECURSOR FLIGHTS**
- 5. EVA TECHNOLOGY NEEDS A MORE VIGOROUS \$ INFUSION TO ASSURE AVAILABILITY, VERIFICATION, AND MULTI-USER NEEDS/DATES**
  - OPPORTUNITY FOR NASA & DoD MUTUAL INVESTMENT BENEFIT**

Theme 8 of 8

## HUMANS IN SPACE

Theme 8 of 8

### 8.1 EVA / Suit

#### *EVA and Pressure Suit Technology*

Prof. David L. Akin  
Massachusetts Institute of Technology

## Background

- **Gemini**
  - Free-floating mobility
  - Experiment collection
  - Investigation of restraints
- **Apollo**
  - Self-contained life support equipment
  - Retrieval of mapping camera film
  - Lunar surface operations
  - Surface transport infrastructure
- **Skylab**
  - Planned servicing of instruments
  - Contingency repairs
- **Shuttle**
  - Satellite retrieval
  - ORU changeout
  - Dexterous repair operations
  - Initial EVA/robotic cooperation
  - Untethered MMU operations
  - Large object handling
  - Unpracticed EVA
  - Structural assembly

## Research Needs

- Development and use of physiological workload measurement systems for neutral buoyancy simulation
- Correlation of physiological workloads between neutral buoyancy and flight
- Calibration of forces required internally to actuate suit joints
- Development of noninvasive neuromuscular instrumentation for quantifying fatigue in critical muscle groups (wrist and hands)
- Development of advanced computer models of EVA with correlation of force, kinematic, dynamic, and workload elements in neutral buoyancy and space flight
- Development of rule-based system for predicting EVA task performance for use as a simplified front-end to "CAD Astronaut" model

Theme 8 of 8

## HUMANS IN SPACE

Theme 8 of 8

### 8.1 EVA / Suit

#### *EVA and Pressure Suit Technology*

Prof. David L. Akin  
Massachusetts Institute of Technology

### Technology Needs

- Gloves with better mobility, dexterity, tactility
- Simplified suit systems for on-site maintenance and refurbishment, extended operational lifetime
- Non-venting cooling system, zone heating and cooling
- Advanced controls and displays, particularly video
- Extended set of available hand and power tools
- Non-Intrusive body joint position and force sensors for biomechanics data collection
- Maneuvering units with additional  $\Delta V$ , single-hand control, and autonomous navigational capability (leading up to astronaut support vehicle/EVA Retriever)
- In-space suit decontamination systems, particularly for hydrazine

### In-Space Experimentation Needs

- Conduct routine EVAs to build experience base and to allow for experimental opportunities
- Baseline the use of suits instrumented for biomechanics and workload measurements to expand quantitative data base on EVA operations
- Conduct a series of fiduciary experiments to determine the limits of human capability in EVA, with and without the use of EVA tools/aids/support systems
- Assess the use of AI technology to provide suit monitoring and error diagnosis, reducing or eliminating the need for mission control monitoring
- As telerobotic systems develop, investigate cooperative roles for EVA and robotics to enhance space operations
- Evolve life support systems towards regenerative technology to allow for extended operations in space or on planetary surfaces
- Assess the use of bidirectional video for reducing crew training requirements
- Investigate the use of telepresence technology to replace neutral buoyancy training for long-duration space crew
- Develop "CAD Astronaut" to allow long-duration space crew to investigate trade-offs in EVA techniques, simplify EVA planning and training, reduce dependence on mission control
- Experimentally verify research applied to innovative high-payoff concepts, such as skinsuit technology

Theme 8 of 8

**HUMANS IN SPACE**  
**8.2 Human Performance**  
***Crew and Environmental Factors***

Theme 8 of 8

**Dr. Barbara G. Kanki**  
NASA Ames Research Center, Crew Research & Space Human Factors

**INTRODUCTION/BACKGROUND  
GOALS**

- "To develop empirically-based scientific principles that identify the environmental, individual, group, and organizational requirements for long-term occupancy of space by humans."  

— Report of the National Research Council  
Committee on Space Biology and Medicine  
("The Goldberg Report"), p. 169
- To develop useful and practical approaches to selecting, training, and organizing effective crews for long duration space missions in collaboration with operational organizations.
- To provide a scientific resource to organizations responsible for man-systems design, crew selection and training and missions operations.

**TECHNOLOGY NEEDS**

**Critical shortage of relevant research.  
No operational guidelines for spaceflight  
or long-term space occupancy.**

**PROBLEM AREAS**

- 1. Individual and Physiological**
- 2. Crew and Interpersonal**
- 3. Organization and Management**
- 4. Training and Intervention**
- 5. Environmental and Task**

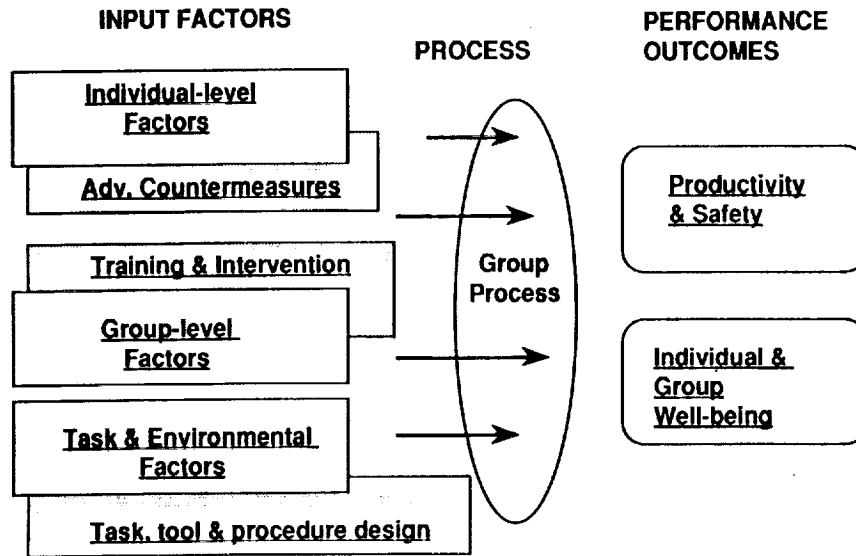
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**HUMANS IN SPACE**  
8.2 Human Performance  
*Crew and Environmental Factors*

Theme 8 of 8

Dr. Barbara G. Kanki  
NASA Ames Research Center, Crew Research & Space Human Factors

**TECHNOLOGY NEEDS**  
Research for Optimizing Human Performance



**CONCEPTUAL FRAMEWORK**

*adapted from McGrath, 1984*

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**Multi-phase Research Plan**

- Laboratory/Mockup Research
- Field Observation
- Systematic Field Research
- Partial Analog Research
- Full-Scale Analog Research

**Relevant Analogous Environments**

- Space Vehicle Analog
- Space Station Analog
- Planetary Exploration Analog
- Astronaut/Mission Control
- Telescience Analog

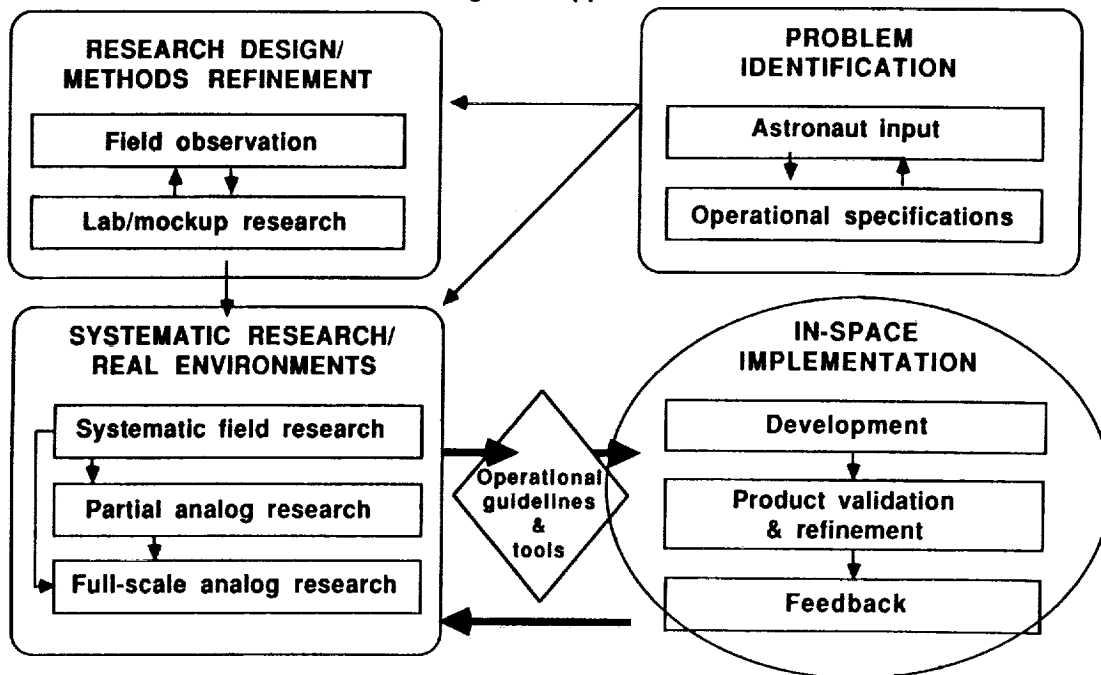
Theme 8 of 8

**HUMANS IN SPACE**  
8.2 Human Performance  
*Crew and Environmental Factors*

Theme 8 of 8

Dr. Barbara G. Kanki  
NASA Ames Research Center, Crew Research & Space Human Factors

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**  
An Integrated Approach



Theme 8 of 8

**HUMANS IN SPACE**  
8.2 Human Performance  
**Artificial Gravity**

Theme 8 of 8

Larry G. Lemke  
NASA Ames Research Center

**INTRODUCTION/BACKGROUND**

- "...THERE APPEARS TO BE A GENERAL PERCEPTION THAT THE ABSENCE OF LIFE-THREATENING MEDICAL PROBLEMS IN THE MANNED SPACE PROGRAM IMPLIES THAT THERE IS LITTLE NEED TO BE CONCERNED ABOUT HEALTH-RELATED ISSUES ON A MANNED SPACE STATION OR IN INTERPLANETARY MISSIONS OF SEVERAL YEARS DURATION. *BASED ON WHAT WE KNOW TODAY, THIS ASSUMPTION OF CONTINUED SUCCESS CANNOT BE RIGOROUSLY DEFENDED*".

--NATIONAL RESEARCH COUNCIL, COMMITTEE ON SPACE BIOLOGY & MEDICINE, 1987--

- "LONG-DURATION HUMAN HABITATION OF THE MOON AND MARS WILL REQUIRE PRIOR LONG-TERM STUDIES OF THE EFFECTS OF EXPOSURE TO 1/6 AND 1/3 G ON ANIMALS AND, EVENTUALLY HUMANS, INCLUDING STUDIES OF MULTIGENERATIONAL EXPOSURE TO VARIED G LEVELS"

•RECOMMENDATION:

A TETHERED (> 10-METER DIAMETER) VARIABLE GRAVITY RESEARCH FACILITY FOR THE SPACE STATION THAT WOULD GREATLY REDUCE CORIOLIS/GRADIENT PROBLEMS ACROSS LARGE ANIMALS AND THAT WOULD BE OPERATIONAL BEFORE THE START OF ANY HUMAN SPACE MISSIONS OF EXTENDED DURATION"

--ROBBINS COMMITTEE REPORT, 1988--

**MISSION APPLICATIONS**

PROBABLE:

- HUMAN MARS EXPLORATION SCENARIOS

POSSIBLE:

- LUNAR BASES
- ADVANCED SPACE STATIONS
- HUMAN ASTEROID RECONNAISSANCE

Theme 8 of 8

**HUMANS IN SPACE**  
8.2 Human Performance  
*Artificial Gravity*

Theme 8 of 8

Larry G. Lemke  
NASA Ames Research Center

**TECHNOLOGY NEEDS**

- DESIGN STRATEGIES, CONTROL ALGORITHMS, & SPECIALIZED ACTUATORS TO ALLOW RELIABLE & SAFE CONTROL OF SPINNING, TETHERED DUMBBELL CONFIGURATIONS

**STRATEGIES,:**

- OPTIMAL MASS DISTRIBUTION
- OPTIMAL ACTUATOR PLACEMENT
- OPTIMAL ACTUATOR TYPE

**ALGORITHMS,:**

- END-BODY ATTITUDE CONTROL
- END-BODY PROPULSIVE THRUSTING CONTROL
- TETHER VIBRATION CONTROL
- TETHER LENGTH CONTROL

**ACTUATORS:**

- END-BODY ATTITUDE CONTROL
- TETHER LENGTH CONTROL

**IN-SPACE EXPERIMENTATION NEEDS**

**EXPERIMENT HARDWARE:**

- SMALL, (~ 1000KG) FREE-FLYING, REMOTELY CONTROLLED , TETHER-CONNECTED DUMBBELL SPACECRAFT
- INSTRUMENTED TO MEASURE ALL IMPORTANT STATE VARIABLES
- ABILITY TO CONTROL SAME DEGREES-OF-FREEDOM AS HUMAN-RATED SPACECRAFT
- ROTATIONAL AND VIBRATIONAL EIGENVALUES CHOSEN FOR DYNAMIC SIMILARITY(TO ALLOW SCALING TO FULL-SIZE FACILITY)

**EXPERIMENT OBJECTIVES:**

- MAINTAIN STEADY-STATE HABITAT G-LEVEL WITHIN +/- 1%, 3-AXIS ATTITUDE WITHIN +/- 1 DEG.
- STABILIZE COUPLED TRANSLATIONAL, ROTATIONAL, AND VIBRATIONAL MODES DURING SPIN-UP, SPIN-DOWN, TRANSLATIONAL THRUSTER FIRINGS
- CONTROL TRANSLATIONAL DELTA-V WHILE SPINNING TO < 1 m/s (INCLUDING PLANE CHANGES)
- DEMONSTRATE RECOVERY FROM FAILURES

Theme 8 of 8

**HUMANS IN SPACE**  
8.2 Human Performance  
*Artificial Gravity*

Theme 8 of 8

**Larry G. Lemke**  
NASA Ames Research Center

**SUMMARY/RECOMMENDATIONS**

- HUMAN EXPLORATION MISSIONS MAY REQUIRE ARTIFICIAL GRAVITY
- VERY LARGE RADIUS ( $\approx 225$  m) CENTRIFUGE SEEMS MOST CONSERVATIVE FROM BIOLOGICAL PERSPECTIVE, MOST CHALLENGING FROM TECHNOLOGICAL PERSPECTIVE
- CONTROL OF LARGE, HIGHLY FLEXIBLE, ROTATING SYSTEMS MUST BE SHOWN SAFE AND RELIABLE PRIOR TO HUMAN-RATING
- EXPERIMENT OBJECTIVES CAN BE ACHIEVED WITH SUB-SCALE, FREE-FLYING DUMBBELL CONFIGURATION:
- INITIATE FLIGHT EXPERIMENT DEFINITION AND DEVELOPMENT SOON TO BE CONSISTENT WITH OVERALL AGENCY SCHEDULE
  - LABORATORY RESEARCH, SIMULATION, & ANALYSIS
  - CONCEPTUAL DEVELOPMENT OF FLIGHT HARDWARE

Theme 8 of 8

**HUMANS IN SPACE**  
8.2 Human Performance  
*Human Performance*

Theme 8 of 8

William R. Ferrell  
University of Arizona, Systems & Industrial Engineering Dept.

**INTRODUCTION / BACKGROUND**

**HUMAN PERFORMANCE :** Human characteristics that affect the design of tasks, human-system interfaces, training

**NASA SUCCESS IN DESIGN FOR HUMAN PERFORMANCE**

- Humans in space
- Ground control of remote operations

**ROLES OF HUMANS IN SPACE WILL CONTINUE TO CHANGE**

- Passenger to Experimenter to Scientist / Engineer
- Passive to Active
- Sensory - motor skills to Decision - making / Problem - solving

**CURRENT BASES FOR DESIGN - will have to evolve**

- NASA & Contractor experience
- Data & standards compilations, e.g. MSIS & MSRB
- Models for dynamic manual control
- Models for routine cognitive skills, motor skills, sensory function
- Simulation methods for crew activity and work load analysis
- Guidelines for computer - human interface design
- Beginnings of useful models for cognitive performance of specific tasks, e.g., debugging, transfer of procedural training

**HUMAN FACTORS FIELD**

- Uneven development and too little basic research
- Focus on skills, task components

**MISSION APPLICATIONS**

- Multi-way, interpersonal communication with voice, text and images
- High - dexterity manipulation
- Monitoring of intelligent monitoring systems
- Skill maintenance and training
- Data Interpretation and analysis
- Information retrieval, storage and management tasks
- Intervention in and redirection of experiments
- Participation in revising old and devising new experiments
- Equipment repair
- Cooperative, creative problem solving and strategic decision making

Theme 8 of 8

**HUMANS IN SPACE**  
8.2 Human Performance  
*Human Performance*

Theme 8 of 8

William R. Ferrell  
University of Arizona, Systems & Industrial Engineering Dept.

**TECHNOLOGY NEEDS**

**COMPUTER - BASED, INTELLIGENT SUPPORT FOR :**

- Problem solving and diagnosis
- Decision making
- Information management
- Monitoring of systems and environments
- Skill maintenance and learning
- Cooperative work with voice, text and images

**ENABLING TECHNOLOGIES:**

- Dynamic management of multi-media, multi-channel computer-human communication
- Language (and spoken language) understanding systems
- Intention Inference
- Image and geometry understanding systems

**DESIGN TECHNOLOGIES:**

- Task analysis and simulation
- Rapid prototyping
- Integrated human performance models incorporating responses to the space environment

**IN - SPACE EXPERIMENTS NEEDS / VOIDS**

Most of the technology for supporting human performance in space can be developed and tested without in-space experimentation.

In-space experimentation is important for:

- Design technologies, to determine / verify space environment effects on performance
- Specific interface design proposals, to assess interactions among task, interface, habitat, work-station and crew characteristics in the space environment -- early in the design process.

Need to begin early to develop the research base for design of effective support for distinctively human role in space.

Theme 8 of 8

**HUMANS IN SPACE**  
**8.2 Human Performance**  
***Human Performance***

Theme 8 of 8

William R. Ferrell  
University of Arizona, Systems & Industrial Engineering Dept.

**SUMMARY / RECOMMENDATIONS**

**ROLES:** Science, Monitoring, Diagnosis, Intervention, Repair

**NEED KNOWLEDGE-BASED TECHNOLOGIES to support:**

- Creative Problem Solving
- Unforeseen Activities
- Intervention and Repair
- Cooperative Planning & Decision

**SUBSTANTIAL SUPPORT FOR GROUND - BASED RESEARCH IS  
NEEDED TO DEVELOP THESE TECHNOLOGIES**

**IN - SPACE EXPERIMENTATION:**

- Physiological / Perceptual / Anthropometric modeling
- [ Habitat & EVA experiments ] (related sub - themes)
- [ TELEOPERATION experiments]
- Multi - operator, cooperative workstations
- Task / Interface simulations for testing interactions in context and for timely design feedback

**NEED FOR AN IN-SPACE FACILITY TO SUPPORT DESIGN**

**CRITICAL ISSUES:**

- Intelligent , dynamic interface management systems
- System integration -- a technical not a management--problem

Theme 8 of 8

## HUMANS IN SPACE

Theme 8 of 8

### 8.3 Closed-Loop Life Support Systems *Physical/Chemical Closed Loop Life Support*

R.D. MacElroy  
NASA Ames Research Center

## Background. . .

### Closed-loop Life Support Focuses:

- Post-Space Station Life Support issues
- Efficient regeneration of life support materials
- Further development of existing technologies
- Promotion of innovative technologies
- Evaluation of new technologies

## Technology Needs

### Life Support Functions / Technologies:

- Collection of CO<sub>2</sub>; adsorber regeneration
- Separation of gases
- Generation of O<sub>2</sub> from H<sub>2</sub>O, CO<sub>2</sub>
- Management and processing waste streams
- Purification of reclaimable water
- Process, sub-system and system sensing, monitoring and control
- Thermal control

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.3 Closed-Loop Life Support Systems**

***Physical/Chemical Closed Loop Life Support***

**R.D. MacElroy**  
NASA Ames Research Center

**In-Space Experimentation Needs:**

- \* **Subsystems will be specifically designed to reduce reliance on gravity and low radiation levels**
  - **However, testing in the space environment will be essential because of long-term human reliance on life support devices**
  - **Physical Integration of subsystem will be simulated; however, validation and verification of In-space behavior is required**
  - **Start-up, shut-down and operational transients must be evaluated in the space environment**

**In-space Experimentation needs:**

- \* **A central issue: gas - liquid separation**
- \* **Related issues:**
  - **liquid behavior on surfaces in low gravity**
  - **changes in thermal behavior caused by differences in the convective behavior of fluids**
- \* **In general, subsystem designs that rely on forced fluid movements will obviate effects caused by decreased gravity**

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**HUMANS IN SPACE**  
8.3 Closed-Loop Life Support Systems  
*Industry Presentation*

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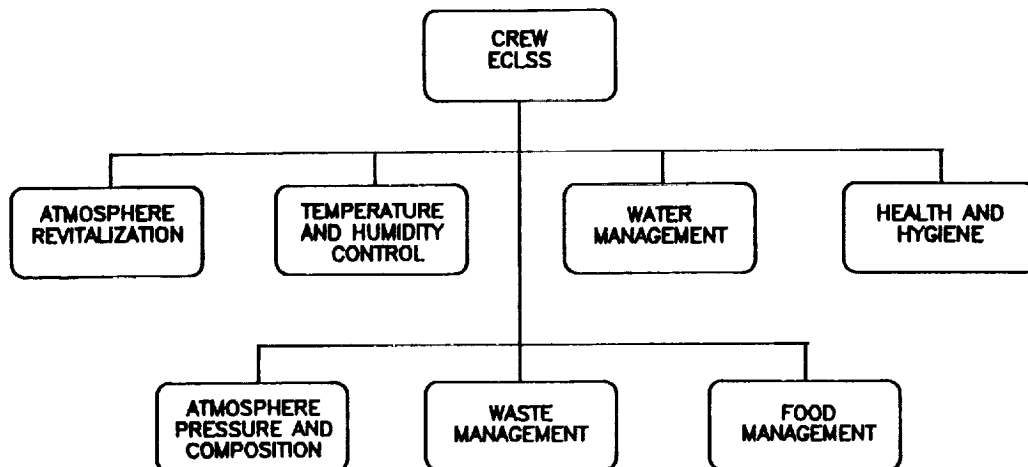
Thomas J. Slavin, P.E.  
Boeing Aerospace, Life Support Engineering

**SYSTEMS TESTS LESSONS LEARNED/ISSUES**

- MATERIALS SELECTION/COMPATIBILITY
- CAREFUL DESIGN OF SYSTEM CLOSURE
- INTEGRATION OF SUBSYSTEMS
- ON-BOARD MAINTENANCE AND SERVICING

**TECHNOLOGY NEEDS**

**LIFE SUPPORT FUNCTIONS**



**LIFE SUPPORT TECHNOLOGY SELECTION DRIVERS**

- OPERATING ENVIRONMENT
  - Gravity fields
  - Ambient pressures
- RELIABILITY/MAINTAINABILITY
- SAFETY
- POWER, MASS, VOLUME
- DEVELOPMENT COST AND SCHEDULE
- RESTRICTIONS ON RESUPPLY, EXPENDABLES, DISCHARGES

Theme 8 of 8

**HUMANS IN SPACE**  
8.3 Closed-Loop Life Support Systems  
*Industry Presentation*

Theme 8 of 8

Thomas J. Slavin, P.E.  
Boeing Aerospace, Life Support Engineering

**IN-SPACE EXPERIMENTATION NEEDS/VOIDS**

**PHYSICAL-CHEMICAL LIFE SUPPORT TECHNOLOGY**

<b>FUNCTION</b>	<b>TECHNOLOGY AREA</b>	<b>NEED</b>
<b>WATER RECLAMATION</b>	<ul style="list-style-type: none"> <li>• Liq/Air Separation</li> <li>• Solids Separation</li> <li>• Fluid Transport</li> </ul>	<ul style="list-style-type: none"> <li>• Passive Separation Devices</li> <li>• Filter Solids Accumulation</li> <li>• Wicking Devices</li> </ul>
<b>WASTE MANAGEMENT</b>	<ul style="list-style-type: none"> <li>• Pre-Treatment</li> <li>• Solids Reduction</li> </ul>	<ul style="list-style-type: none"> <li>• Effectiveness of Antifoam in 0 g</li> <li>• Low Temp/Energy Processes</li> </ul>
<b>AIR REVITALIZATION</b>	<ul style="list-style-type: none"> <li>• Catalytic Reactors</li> <li>• Electrochemical Cells</li> </ul>	<ul style="list-style-type: none"> <li>• Mixing &amp; Heat Dissipation</li> <li>• Behavior of light gases &amp; thermal gradients</li> <li>• Behavior of flames &amp; plasmas</li> <li>• Change in efficiency</li> </ul>

**CONTROLLED ECOLOGICAL/BIOREGENERATIVE LIFE SUPPORT TECHNOLOGY**

<b>FUNCTION</b>	<b>TECHNOLOGY AREA</b>	<b>NEED</b>
<b>FOOD, OXYGEN, &amp; WATER PROD.</b>	<ul style="list-style-type: none"> <li>• Lighting</li> <li>• Nutrients</li> <li>• Plant Growth</li> </ul>	<ul style="list-style-type: none"> <li>• Sun light collection, filtering, and distribution from orbiting platform</li> <li>• Nutrient solution delivery</li> <li>• Incremental Introduction of plants on Space Station program</li> </ul>
<b>FOOD PROCESSING</b>	<ul style="list-style-type: none"> <li>• Conversion</li> </ul>	<ul style="list-style-type: none"> <li>• Glycerol &amp; protein extraction</li> <li>• Biological conversion processes</li> </ul>
<b>WASTE PROCESSING</b>	<ul style="list-style-type: none"> <li>• Bioregeneration</li> </ul>	<ul style="list-style-type: none"> <li>• Biodigestion in 0 g</li> <li>• Gas/liquid/solid separation</li> </ul>
<b>AUTOMATION &amp; CONTROL</b>	<ul style="list-style-type: none"> <li>• Instrumentation Design</li> </ul>	<ul style="list-style-type: none"> <li>• Gravity independent sensor dev.</li> <li>• Struct dsn (minimize dead spaces)</li> </ul>

Theme 8 of 8

## **HUMANS IN SPACE**

Theme 8 of 8

### **8.3 Closed-Loop Life Support Systems**

#### ***Physical/Chemical Closed-Loop Life Support***

**Marvin W. Luttgies / Louis Stodieck**

University of Colorado, Aerospace Engineering Sciences and Bioserve Space Technologies

## **INTRODUCTION/BACKGROUND**

**LIFE SUPPORT RESUPPLY REQUIREMENTS SERIOUSLY  
CONSTRAIN MANNED SPACE MISSIONS.**

## **CURRENT TECHNOLOGIES**

- \* PROVIDE FOR LITTLE RE-USE**
- \* ARE COSTLY**
- \* INHIBIT SPACE MISSION FLEXIBILITY**
- \* ARE NOT WELL-DEVELOPED**
- \* HAVE TECHNICAL AND SAFETY DRAWBACKS**

## **TECHNOLOGY NEEDS**

### **ORBITAL/TRANSIT NEEDS**

- \* REDUCED WEIGHT, POWER AND HEAT**
- \* EFFICIENCY**
- \* SAFETY**
- \* MICROGRAVITY-EFFECTIVE SUBSYSTEMS**
- \* INTEGRATION**

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.3 Closed-Loop Life Support Systems**

***Physical/Chemical Closed-Loop Life Support***

**Marvin W. Luttgies / Louis Stodleck**

University of Colorado, Aerospace Engineering Sciences and Bioserve Space Technologies

**TECHNOLOGY NEEDS**

**SURFACE NEEDS**

- \* **TRANSPORTATION**
- \* **SURFACE RESOURCE USE**
- \* **AUTONOMY AND RELIABILITY**
- \* **PRODUCT MANAGEMENT**
- \* **POWER**

**IN-SPACE EXPERIMENTATION NEEDS**

**ORBITAL/TRANSIT NEEDS**

- \* **FLUID SUBSYSTEM TESTS**
- \* **MASS VS. CONTAINMENT TRADES**
- \* **MICROGRAVITY SENSORS AND CONTROL**
- \* **SURFACE/CATALYTIC EFFICIENCIES**
- \* **RELIABILITY**
- \* **POWER AND HEAT REDUCTIONS**

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.3 Closed-Loop Life Support Systems**

***Physical/Chemical Closed-Loop Life Support***

**Marvin W. Luttgies / Louis Stodleck**

University of Colorado, Aerospace Engineering Sciences and Bioserve Space Technologies

**IN-SPACE EXPERIMENTATION NEEDS**

**SURFACE NEEDS**

- \* ON-SITE RESOURCE USES/TESTS**
- \* LONG-TERM AUTONOMY AND RELIABILITY**
- \* TRANSPORT AND DEPLOYMENT TESTS**
- \* PRODUCT STORAGE, DISTRIBUTION AND USE**
- \* POWER**

Theme 8 of 8

## HUMANS IN SPACE

Theme 8 of 8

### 8.3 Closed-Loop Life Support Systems

#### *Humans in Space Critical Technology Requirements*

Ramus Bretol  
NASA Ames Research Center

### EVA / SUIT

- o DEVELOP THE TECHNOLOGY FOR MEASUREMENT OF EVA FORCES, MOMENTS, DYNAMICS, PHYSIOLOGICAL WORKLOAD, THERMAL LOADS AND MUSCULAR FATIGUE.
- o EVALUATE COOPERATIVE ROLES BETWEEN EVA AND TELEROBOTS AND FOR IVA AND ROBOTICS.
- o SUIT CONTAMINANTS DETECTION, IDENTIFICATION AND REMOVAL.

### HUMAN PERFORMANCE

- o TECHNOLOGY FOR MEASUREMENT OF GRAVITY-RELATED ADAPTATION AND RE-ADAPTATION BEHAVIOR
- o TECHNOLOGY FOR IN-SPACE ANTHROPOMETRIC AND PERFORMANCE MEASUREMENT
- o VARIABLE - GRAVITY FACILITY AND APPLICATION TECHNOLOGY

Theme 8 of 8

**HUMANS IN SPACE**

Theme 8 of 8

**8.3 Closed-Loop Life Support Systems**

***Humans in Space Critical Technology Requirements***

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**CLOSED LOOP LIFE SUPPORT SYSTEMS**

- o IMPROVED PHASE SEPARATION SYSTEMS
- o GRAVITY-INDEPENDENT SENSOR SYSTEMS
- o WASTE-CONVERSION PROCESSES
- o FLUID MIXING AND COMPOSITION CONTROL
- o REACTOR PHENOMENA
- o CHEMICAL SPECIES SEPARATION

**OTHERS TO CONSIDER - POSSIBLY  
BY OTHER THEMES**

- o FIRE AND SMOKE DETECTION SYSTEM
- o ZERO-G PHASE CHANGE PHENOMENA FOR EVA  
THERMAL MANAGEMENT
- o FOAMING COUNTERMEASURES



## Report Documentation Page

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16. Abstract  The purpose of the OAST In-STEP 88 Workshop was to identify and prioritize technologies that are critical for future national space programs and require validation in the space environment, and review current NASA (In-Reach) and Industry/University (Out-Reach) experiments. A prioritized list of the critical technology needs was developed for the following 8 disciplines: Structures; Environmental Effects; Power Systems and Thermal Management; Fluid Management and Propulsion Systems; Automation and Robotics; Sensors and Information Systems; In-Space Systems and Humans in Space.  Part 2 contains the critical technology presentations for the eight theme elements (space structures, space environmental effects, power systems and thermal management, and fluid management and propulsion systems, automation and robotics, sensors information systems, in-space systems, and humans in space) and a summary listing of critical space technology needs for each theme.			
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